

P-864

# National Facilities Study

(NASA-TM-109856) NATIONAL  
FACILITIES STUDY. VOLUME 2A:  
FACILITY STUDY OFFICE ON THE  
NATIONAL WIND TUNNEL COMPLEX Final  
Report (NASA) 864 p

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## Facility Study Office on the National Wind Tunnel Complex Final Report

### Volume 2A

April 29, 1994

NASA  
Washington, D. C.





Reply to Attn of:

112

January 11, 1994

TO: 102/Chairman, Aero-Facilities Task Group  
FROM: 112/Head, Facilities Study Office  
SUBJECT: Facilities Study Office Final Report

The Facilities Study Office (FSO) was formed as an organization in May of 1993 to provide timely development, reviews, and assessments of concepts and costs associated with the new National Wind Tunnel Complex (NWTC). The assessments of the NWTC were required to support the joint NASA/DOD/Industry Aero Facilities Task Group (AFTG). The FSO was an inter-agency organization with personnel from NASA (LaRC and ARC), DOD (Arnold Engineering Development Center), and the Army Corps of Engineers (Mobile District). This group formed a core team of dedicated professionals who developed, collated, and assessed the various options for the NTWC.

#### FSO Charter

1. Provide an independent assessment of the costs (capital costs, operating costs, and life cycle costs) for the Boeing-derived wind tunnel complex (noted herein as Concept A). Note that these are the requirements and configuration of the Boeing project as understood by the FSO personnel.
2. Provide an independent assessment of the technical merit of the Boeing-derived wind tunnel complex.
3. Provide independent assessments of alternative concepts for the NWTC; cost (capital costs, operating costs, and life cycle costs), schedule, concept definition, and technical merit (noted herein as Concepts A-Modified, B, C, and D and their derivative options).
4. Present the information to the AFTG in a timely manner for concept selection to support submission of the selected concept into the FY 95 NASA budget.
5. Develop preliminary project planning information for the NWTC Project Office.



### Summary of FSO Activities

The FSO existed as a dedicated staff function from May 1993 through December 1993. During that time assessments of concepts were performed, site selection activities were performed, identification and assessments of critical technologies required and the areas of high technical risk were identified and assessed, and preliminary project plans were developed.

Cost and technical assessments of five (5) base concepts were developed. These were identified as Concept A (the Boeing project as understood by the FSO personnel), Concept A-Modified, Concept B (the National Consensus Concept), Concept C, and Concept D. Differentiators between the concepts are provided in the Final Report (Attachment 3). Options from the base concepts were also assessed from a cost and technical standpoint. Five (5) concepts that were derivatives of Concept A-Modified, two (2) concepts that were derivatives of Concept B, and eight (8) concepts that were derivatives of Concept D were assessed.

The AFTG selected Concept D-Option 5 as the cost baseline for the NTWC. The specific results of the assessment of Concept D - Option 5 are provided in Table 1. An Ad-Hoc review panel was selected to review the cost and technical assessments that were performed. The review panel had technical assistance from the Sverdrup Technologies, Inc. The Ad-Hoc review panel supported the FSO cost estimate for the selected concept.

Other FSO activities were associated with development of the site selection plans. The proposal for the Offerors, the Site Selection Board Evaluation Plan, preliminary rating factors, and numerous other activities associated with the site selection planning were developed. Specific selection of a site was not made.

Identification of areas of high technical risk and areas requiring technological development were identified. Plans for performing the numerous required studies were developed including descriptions of the areas of investigation, preliminary statements of work, acquisition strategies, schedules, and cost estimates.

Preliminary project plans were also developed. The plans included development of contract statements of work, development of program funding profiles, and assessment of various acquisition strategies. While no specific acquisition strategy was recommended, a strategy was used for the cost and schedule assessments. In addition, the relative merits of various acquisition strategies were provided to the AFTG.



## Final Report

The FSO has completed its assigned activities. The results of the FSO efforts, studies, and assessments are documented in the attached final report. The final report is composed of this transmittal letter and 8 attachments. The attachments provide an overview of the FSO activities as well as a general comparison of all concepts considered. Detailed information is provided for the selected concept - Concept D-Option 5.

The final report presents only findings and does not provide any recommendations for concept selection, site selection, acquisition strategy, or program/project management. The FSO developed recommendations only as a consequence of assumptions for cost and schedule assessments. The justification for the NWTC and the recommendations for concept selection, site selection, acquisition strategy, and program/project management strategy are not in this report since these activities fall under the purview of other organizations or committees.

The final report consists of the following attachments:

Attachment 1: Description of the Facilities Study Office.

Attachment 2: A description of the Cost Baseline - Concept D-Option 5. The description includes the top level facility performance and productivity requirements, a description of the concept as it was costed (Work Breakdown Structure Dictionary), program cost estimate, program schedule and annual obligations required, and the productivity, operating cost, and life cycle cost assessments.

Attachment 3: Descriptions of all of the alternative concepts considered. Information similar to the cost baseline description is presented, though not in the detail that is provided for the cost baseline.

Attachment 4: A brief discussion of the results of the two independent assessments performed.

Attachment 5: The Criteria and Requirements Document for the cost baseline Concept D-Option 5

Attachment 6: Identification of and description of the areas of recommended for study.

Attachment 7: The Site Selection Plans, including the plan required for the offerors and the site selection board's evaluation plan and criteria.

Attachment 8: The Project Management issues developed during the FSO activities, including the management structure included in the cost baseline, the proposed Commerce Business Daily Announcements for the studies contract(s) and for the PER and Preliminary Design, and the Statement of Work for PER/Preliminary Design contract.



### Unresolved Issues

The FSO has identified the following critical problem areas that must be resolved as soon as possible:

1. Integration of the external balance into the test sections. The load range, size, and accuracy required are beyond the range of currently fabricated external balances. The balance stiffness necessary to achieve the required accuracy may dictate that the balance be anchored to ground at the test section. The fundamental issue of where the tunnel shell is to be anchored (either at the drive system or the test section or both) drives the entire pressure shell design process. This issue is fundamental to the successful start of the design.
2. Wall interference. The required size of the model could be such that the induced wall interference renders the data uncorrectable using any currently accepted method of wall interference correction. The use of a smaller model will eliminate the wall interference issue, however, this will result in a smaller than advertised Reynolds number. In addition, large models are required to perform testing for high lift devices. Therefore, the wall interference issue needs to be resolved immediately.
3. Site Selection. The selection of the site for the NWTC is crucial to the early success of the project. Site selection can influence factors such as operating cost (and thus cost per polar), access to the site for shipment of large components (build off-site and ship in for site erection, or build on-site), capital cost for labor rates, etc., and any potential cost savings that may be realized due to the use of existing infrastructure. In addition, long term activities such as an Environmental Impact Statement will be required and will influence the NWTC design. Numerous other minor issues are also influenced by the site selection and should not be ignored. Site selection must occur prior to the Preliminary Design Review (approximately 30% design completion) or significant cost and schedule impacts will be realized.

### Summary of Results

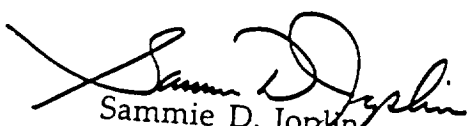
The FSO assessed a number of concepts. The final results are provided in the attached report. The AFTG selected Concept D-Option 5 as the baseline for the NWTC. Final results of the selected concept assessment are:



Table 1: Summary Results for Concept D-Option 5

Parameter	Result
Program Budget Total	\$3,223,393 K
Program Schedule Duration	9.5 years (From FY94 through second Quarter of FY2003)
Total Complex Staff (Permanent)	200
Annual Operating Cost	\$50,967 K
	LSWT \$21,496K
	TSWT \$29,471K
Cost Per Polar:	LSWT \$752
	TSWT \$644

This completes the FSO activities. Any questions concerning this report or requests for additional information should be directed to Kenneth L. Jacobs at 804-864-6967 or Henry S. Wright at 804-864-6928.

  
Sammie D. Joplin  
46028

Enclosures:

- Attachment 1 Facilities Study Office
  - Attachment 1.1 Facilities Study Office Activities
  - Attachment 1.2 Facilities Study Office Keys to Success
- Attachment 2 Cost Baseline Description - Concept D - Option 5
  - Attachment 2.1 Cost Baseline Requirements
  - Attachment 2.2 Cost Baseline Technical Description
  - Attachment 2.3 Cost Baseline Capital Cost
  - Attachment 2.4 Cost Baseline Programmatic Schedule and Annual Funding
  - Attachment 2.5 Cost Baseline Productivity/Operating Cost/Life Cycle Cost
- Attachment 3 Alternative Concepts
  - Attachment 3.1 Alternative Concepts Requirements Comparisons
  - Attachment 3.2 Alternative Concepts Technical Descriptions
  - Attachment 3.3 Alternative Concepts Capital Cost Comparisons
  - Attachment 3.4 Alternative Concepts Productivity/Operating Costs/Life Cycle Cost Comparisons
- Attachment 4 Independent Assessments
- Attachment 5 Criteria and Requirements Document for Concept D - Option 5
- Attachment 6 Description of Areas of Study
- Attachment 7 Site Selection Plan



- Attachment 8 Project Management  
 Attachment 8.1 Program Management  
 Attachment 8.2 Proposed Commerce Business Daily Announcements  
 Attachment 8.3 Statement of Work for PER/Preliminary Design

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**ATTACHMENT 1**  
**NATIONAL WIND TUNNEL COMPLEX**  
**FACILITIES STUDY OFFICE**



**ATTACHMENT 1.1**

**NATIONAL WIND TUNNEL COMPLEX**

**FACILITIES STUDY OFFICE ACTIVITIES**



## FACILITIES STUDY OFFICE

The Facilities Study Office (FSO) was formed in May of 1993 in order to provide an organization capable of providing timely development, reviews, and assessments of concepts and costs associated with the new National Wind Tunnel Complex (NWTC). The assessments of the NWTC were required to support the joint NASA/DoD/Industry Aero-Facilities Task Group (AFTG).

### FSO Charter

1. Provide an independent assessment of the costs (capital costs, operating costs, and life cycle costs) for the Boeing derived wind tunnel complex (noted herein as Concept A). Note that this is as the FSO understood the Boeing project status at the project termination.
2. Provide an independent assessment of the technical merit of the Boeing derived wind tunnel complex.
3. Provide independent assessments of alternative concepts for the NWTC; cost (capital costs, operating costs, and life cycle costs), schedule, concept definition, and technical merit (noted herein as Concepts A-Modified, B, C, and D and their derivative options).
4. Present the information to the AFTG in a timely manner for concept selection to support submission of the selected concept into the FY95 NASA budget.
5. Develop preliminary project planning information for the NWTC Project Office.

### Team Composition

The FSO was an inter-agency team. Personnel from NASA (LaRC and ARC), DoD (Arnold Engineering Development Center - Civil Servants and Operating Contractor personnel), and the Army Corps of Engineers formed a core team of dedicated professionals who developed, collated, and assessed the various options for the NWTC. The team members are provided in Table 1.

### Summary of FSO Activities

**May 5, 1993:** The FSO was chartered by the Chairman of the AFTG (Deputy Director of Langley Research Center). The FSO was staffed with personnel from LaRC, ARC, DoD (Arnold Engineering Development Center - Civil Servants and Contractor Operations Personnel), and the Army Corps of Engineers. The team members were co-located at Langley Research Center beginning in early May 1993. Due to the shortage of NASA travel funds, the ARC personnel resided at Ames and traveled to LaRC periodically to participate in key events. It should be noted that the Ames personnel continued to perform FSO activities while still back at Ames.

**May-June 1993:** Concept A was assessed and found to be lacking technically and financially. Costs were developed by the FSO for Concept A. A contract was awarded through the ARC Bentley Engineering contract to Fluidyne Engineering Corporation to provide a detailed cost breakdown of the Concept A as it was understood by the A/E's when Boeing terminated their activities. The FSO and Fluidyne costs were compared with the Fluidyne contract team and significant differences were noted (some were resolved).

Concept A-Modified was developed by the FSO to correct the technical deficiencies in the original Boeing concept as assessed against the requirements that were known at the time.

The AFTG Working Group developed Concept B (more commonly known as the National Consensus Option). FSO assessed the technical merits and developed costs for the Concept B and its derivative options.

FSO developed Concept C to provide a lower cost alternative to Concept B while expanding the capabilities of Concept A and A-Modified. FSO developed costs for Concept C.

**July 1993:** The results of the FSO cost and technical assessments as well as the project management and program planning information and site selection plans was presented to the AFTG. The AFTG and the AFTG Working Group developed the Concept D requirements and requested that the FSO develop technical and cost assessments for this concept.

The preliminary planning for the Non-Advocate Review began. A contract with Sverdrup Technologies to provide consultant services to the NAR was placed through the LaRC Sverdrup contract. FSO developed technical and cost assessments for Concept D and its derivative options.

**August 1993:** The NAR (or Ad-Hoc Review) was conducted in early August. The FSO and Sverdrup personnel compared costs and technical assessments of Concepts A, A-Modified, and A-Modified Options. The costs were compared and significant differences were noted (some were resolved). The NAR activity continued with the cost and technical comparison for Concept D. The NAR board supported the FSO cost and schedule for the NWTC. The results of the FSO cost and technical assessments for Concept D as well as the project management and program planning information were presented to the AFTG. The AFTG selected Concept D-Option 5 as the preferred option as the NWTC cost baseline.

**September 1993:** The NWTC was presented to the Aeronautics and Space Engineering Board. FSO activities continued for the identification and planning for the critical studies and the development of the appropriate project planning documentation.

**October - December 1993:** FSO activities continued for the identification and planning for the critical studies and the development of the appropriate project planning documentation and the project Criteria and Requirements Document. The final report to the AFTG Chairmen was developed. The FSO was terminated as a dedicated staff function on December 3, 1993.

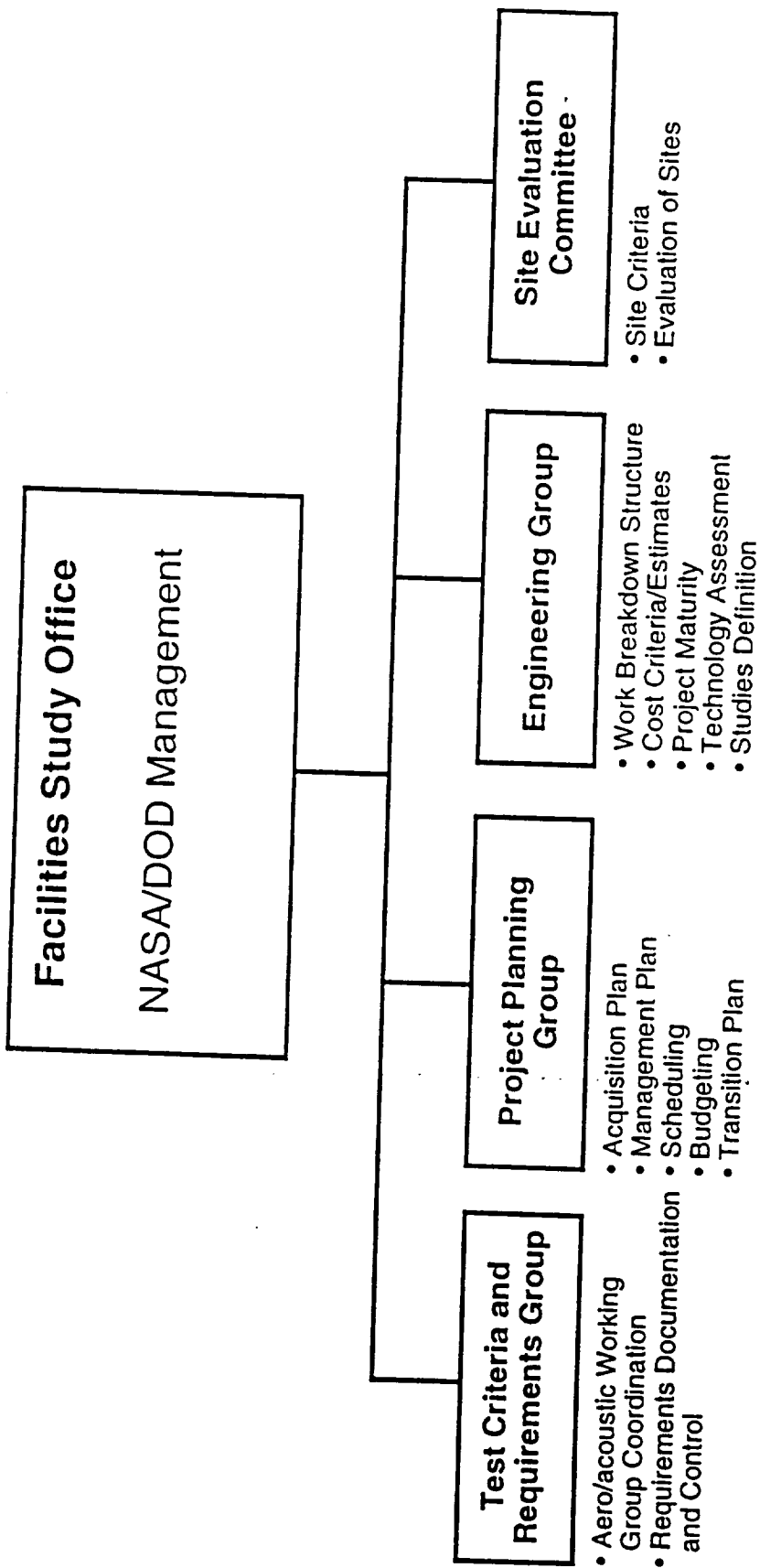
A schedule of the FSO activities is provided as Figure 1.

**TABLE 1: FACILITIES STUDY OFFICE PERSONNEL**

<b><u>Name</u></b>	<b><u>Telephone Number</u></b>	<b><u>Mail Stop</u></b>
<b>NASA - Langley Research Center</b>		
Sammie D. Joplin, (Office Head)	(804) 864-6028	112
Kenneth L. Jacobs, (Deputy Head)	(804) 864-6967	442
George W. Ivey, Jr., (Chief Engineer)	(804) 864-7291	436
Earl R. Booth, Jr.	(804) 864-3627	461
Dennis E. Fuller	(804) 864-5129	267
Blair B. Gloss	(804) 864-3520	285
Drew Hagemann (Lockheed)	(804) 864-7055	356
Carl E. Horne	(804) 864-7260	451
Pendleton M. Jackson, Jr.		
Dr. Seun K. Kahng	(804) 864-7553	235
Charles C. Laney, Jr.	(804) 864-4611	236
Henry L. Livas, Jr.	(804) 864-6837	447
Harry L. Morgan, Jr.	(804) 864-1069	286
Thomas J. Quenville	(804) 864-6935	439
Tricia L. Romanowski	(804) 864-7020	429
John T. Taylor	(804) 864-6924	441
Robert J. Wallis	(804) 864-7228	435
George D. Ware (Vigyan)	(804) 864-5165	267
Brenton W. Weathered	(804) 864-7145	432
Henry S. Wright	(804) 864-6928	443
Norma F. Davis, Secretary		
<b>Arnold Engineering Development Center (AEDC)</b>		
James Y. Parker, (Deputy Head)	(615) 454-3550	
Travis W. Binion, Calspan Corp.	(615) 454-7716	
Lowell C. Keel, Calspan Corp.	(615) 454-7360	
Philip B. Stich, Calspan Corp.	(615) 454-6142	
<b>NASA - Ames Research Center</b>		
Kenneth W. Mort, (Deputy Head)	(415) 604-5483	213-1
James M. Corliss	(415) 604-5457	213-4
Lado Muhlstein, Jr.,	(415) 604-5852	227-4
Dr. Frank W. Steinle, Jr.	(415) 604-5848	227-5
Dan Petroff	(415) 604-5850	
Nina Scheller	(415) 604-4889	
Terry Lusby	(415) 604-6392	
<b>Army Corps of Engineers</b>		
Mobile District - Mobile, AL		
Paul Pamer	(205) 694-3750	

# Facilities Study Office

## Organization



# NATIONAL WIND TUNNEL COMPLEX Facilities Study Office Timeline

ID	Name	Apr '93			May '93			Jun '93			Jul '93			Aug '93			Sep '93			Oct '93			Nov '93			Dec '93																		
		11	18	25	2	9	16	23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28	5	12	19	26	2				
1	Duration of Staffed FSO																																											
2	Formation of FSO																																											
3																																												
4	AFTG Meetings																																											
11																																												
12	Concept Development																																											
13	Concept A																																											
14	Concept A-Modified																																											
15	Concept B																																											
16	Concept C																																											
17	Concept D																																											
18																																												
19	Cost Updates																																											
27																																												
28	Reviews																																											
29	Fluidyne - Concept A																																											
30	Sverdrup - Concepts A, A-Mod, & C																																											
31	Ad-Hoc Review																																											
32																																												
33	Studies																																											
34	Define and Prioritize																																											
35	Task/SOW Statements																																											
36																																												
37	Final Documentation																																											
38	Criteria & Requirements Document																																											
39	Final Report																																											

**ATTACHMENT 1.2**  
**NATIONAL WIND TUNNEL COMPLEX**  
**FACILITIES STUDY OFFICE**  
**KEYS TO SUCCESS**



## FACILITIES STUDY OFFICE KEYS TO SUCCESS

The Facilities Study Office was able to develop in a timely manner a large amount of documentation concerning the National Wind Tunnel Complex. The methods that allowed the staff to succeed can be attributed to a few key elements.

1. Co-Location of Personnel - This can be considered one of the fundamental elements of success. All of the FSO personnel were moved to temporary offices at the start of the office. Personnel remained at the temporary office until either their function was complete or until the office was disbanded. Co-location of personnel and removal of all of their other work assignments allowed personnel to focus on the task. In addition, the synergy that can be realized by having personnel able to talk at length without the filtering effect of travel or the telephone provided an atmosphere that allowed good communications.
2. Professional Approach - Everyone in the office performed as a dedicated professional. A strong work ethic was exhibited by all personnel. No one in the office caused disruption or management problems. This provided a healthy environment for all personnel to focus on the task without having to be concerned about those management issues. There were numerous professional disagreements, however, these were always resolved. Note that while consensus was desirable, it was not always achieved. The lack of consensus on all decisions is not a negative issue, this shows the willingness of the personnel who were responsible to "stand-up" and accept the responsibility for their decisions.
3. Management, Guidance, and Leadership - The FSO management team provided guidance and leadership. The management team provided the goals and objectives and the required guidance. Then the management team "got out of the way," and let the work get done.
4. Prolific Use of Electronic Media - The office relied almost solely on electronic media. The office standardized immediately on the following applications:
  - Word Processing - Microsoft Word
  - Spreadsheets - Microsoft Excel
  - Presentations - Microsoft Powerpoint
  - Presentation Graphics - MacDraw Pro
  - Drafting - AutoCAD
  - Scheduling - Microsoft Project

The office used a combination of both PC's and Macintosh computers. The use of commercially available conversion programs allowed for easy conversion from the PC format for one of the above applications to the Macintosh version of the application or vice-versa. The use of electronic media allowed all personnel to share information. Numerous times, previous versions were edited to suit the new purpose and thus saved an inordinate amount of time that would have been required to create a new file. In addition, all cost data was tracked by the WBS element (to at least the 4th tier). In this manner, it was possible to shift costs, ratio costs, or perform whatever operation was required to develop revised cost estimates.

5. Specific Goals and Objectives - From the outset, the FSO had clearly defined objectives and goals - determine costs for the NWTC concepts. At times, the requirements were very fluid. This provided for changes or revisions to the goals, but they were always met. In addition, delivery schedules and personnel assignments were developed for all of the goals and objectives. This allowed all office personnel to know very clearly which items had the priority, the order for them to be worked, and how to assist in the sharing of the work load.
6. Ample Use of Brainstorming and Planning Sessions - The FSO made great use of brainstorming and group planning sessions. General meetings were used to generate ideas, concepts, and methods. The goal was always to keep the meetings short and focused and allow sufficient time for the ideas to be brought out and discussed to the required extent without overkill. The use of action items and small decision groups allowed for a quicker response to issues and questions.
7. Experience of Personnel - The FSO was staffed with personnel with experience ranging from 11 years to 40 years experience. In addition, the skill mix was varied. The experience included personnel with Wind Tunnel Operations, Wind Tunnel Design (all disciplines), Aerodynamics, Acoustics, Project Management, and Contracts/Acquisition experience. The total experience load for the office for the co-located personnel exceeded 450 man-years of experience, with a staff of 20, this corresponds to an average experience level of 22.5 years.

A systems engineering approach was attempted to be applied to all assessments. This means that the ramifications of a change on other systems/components or on the program as a whole were assessed in conjunction with the assessment of a particular system or element.

8. Documentation of Assumptions and Results - The FSO personnel attempted to document all of the fundamental assumptions that were used in developing cost estimates, technical assessments, or concept

development. This allowed everyone to understand the basis for any decisions that were made so that the ramifications of future changes could be readily understood.



**ATTACHMENT 2**  
**NATIONAL WIND TUNNEL COMPLEX**  
**COST BASELINE DESCRIPTION**  
**CONCEPT D - OPTION 5**



**ATTACHMENT 2.1**  
**NATIONAL WIND TUNNEL COMPLEX**  
**COST BASELINE REQUIREMENTS**



# NATIONAL WIND TUNNEL COMPLEX - COST BASELINE REQUIREMENTS

## **Performance Requirements**

Performance Requirements		Low Speed Wind Tunnel	Transonic Speed Wind Tunnel
Performance Curves		See Figure 1	See Figure 4
Mach Number Range		0.05 to 0.6	0.05 to 1.5
Total Pressure Range		0.07 to 5 atm	0.07 to 5 atm
Test Section Shape		Rectangular, With Fillets	Rectangular, No Fillets
Test Section Size		20 x 24 ft With 5 ft. fillets (Area = 430 ft <sup>2</sup> )	11 x 15.5 ft - 170.5 ft <sup>2</sup>
Test Section Length		30 feet	15 feet
Reynolds Number Reference Length (cbar)		2.19 feet ( $cbar = 0.1 \sqrt{A_{ts}}$ )	1.31 feet ( $cbar = 0.1 \sqrt{A_{ts}}$ )
Maximum Temperature °F		Ambient + 30°	Ambient + 30°F
Test gas		air	Air
Drive Power Design Point		M = 0.3, Pt = 5 atm, Tt = 100°F, Model Drag of 24,000 lbs	M = 1.0, Pt = 5 atm, Tt = 100°F, Model Drag of 11,000 lbs
Maximum Reynolds Number (at Drive Power Design Point)		20.4 Million (based on cbar)	28.1 Million (based on cbar)

## **Acoustic Requirements**

Acoustic Requirements		Low Speed Wind Tunnel	Transonic Speed Wind Tunnel
In-Flow and Out-of-Flow Noise Specifications		See Figure 2	See Figure 5
Anechoic Chamber		Yes, For Open Jet Test Capability	No
Acoustic Frequency Range		100-20,000 Hz	100-20,000 Hz
Open Jet Length		45 feet	N/A
Maximum Measurement Radius		40 feet	N/A
Directivity Angles		60° forward to 70° aft	N/A
Total Pressure During Acoustic Testing		One atmosphere	0.07 to 1 atmosphere
Test Section Type		Open Jet	Closed Jet

## Productivity Requirements

Productivity Requirements	Low Speed Wind Tunnel	Transonic Speed Wind Tunnel
Average Productivity Rate Using Benchmark Test Program (See Appendix A.4)	5 Polars/Occupancy Hour	8 Polars/Occupancy Hour
Removable Plenum and Test Section Carts	Yes	Yes
Cart Quantities and Types	4 (1 Slotted Rear Sting, 2 Slotted Floor Mount, 1 Open Jet Support)	4 (2 Slotted Rear Sting, 1 Slotted Floor Mount, 1 Acoustic Strut Support)
Tunnel Pressure Isolation System	Yes	Yes
Test Annual Throughput (i. e., number of models/tests per year)	TBD	TBD

## Model Propulsion Simulation Requirements

Model Propulsion Requirements	Turbine Power Simulator	High Bypass Simulator	HSCT (Simultaneous) Outer/Inner	Fighter
Use Location	LSWT & TSWT	LSWT & TSWT	LSWT Only	LSWT & TSWT
Mass Flow Rate, lbs/sec	35	30	40/40	100
Temperature At Model, °F	400	200	500/1500	200
Pressure At Model, psia	3000	300	150/150	2500
Run Distribution	Continuous	Continuous	Continuous	15 Minutes Out Of Every 30 Minutes

## Flow Quality Requirements

Data Quality Requirements		Low Speed Wind Tunnel	Low Speed Wind Tunnel	Transonic Speed Wind Tunnel
Flow Quality		Closed Jet	Open Jet	Closed Jet
Test Volume for Flow Quality Requirements		See Figure 3	See Figure 3	See Figure 6
Total Temperature Distribution		$\pm 1.0^{\circ}\text{F}$ , Within Test Volume	$\pm 1.0^{\circ}\text{F}$ , Within Test Volume	$\pm 1.0^{\circ}\text{F}$ , Within Test Volume
Turbulence, %		0.04 Longitudinal, 0.08 Vertical, 0.08 Lateral, Within Test Volume	0.2 Longitudinal, 0.12 Vertical, 0.12 Lateral, Within Test Volume	0.04 Longitudinal, 0.08 Vertical, 0.08 Lateral, Within Test Volume
Noise, RMS		59.4 dB, Within Test Volume	59.4 dB, Within Test Volume	95.0 dB, Within Test Volume
Stream Angle Deviation		$< \pm 0.1^{\circ}$ , Within Test Volume	<i>TBD</i> , Within Test Volume	$< \pm 0.1^{\circ}$ , Within Test Volume
Stream Angle Gradient		$0.01^{\circ}/\text{ft}$ , Along Any Line Within Test Volume	<i>TBD/ft</i> , Along Any Line Within Test Volume	$0.01^{\circ}/\text{ft}$ , Along Any Line Within Test Volume
Mach Number Distribution		$\pm 0.001$ Along Tunnel Centerline $\pm 0.001$ In a Cross Section At Center Of Model Rotation $\pm 0.0005/\text{ft}$ Along Centerline Over Length Of Test Volume	$\pm \text{TBD}$ Along Tunnel Centerline $\pm \text{TBD}$ In a Cross Section At Center Of Model Rotation $\pm \text{TBD/ft}$ Along Centerline Over Length Of Test Volume	$\pm 0.001$ Subsonic, Along Tunnel Centerline $\pm 0.01$ Supersonic, Along Tunnel Centerline $\pm 0.001$ In a Cross Section At Center Of Model Rotation $\pm 0.0005/\text{ft}$ Along Centerline Over Length Of Test Volume
Tunnel Stability: Total Pressure Total Temperature Mach Number		$\pm 1$ psf Over a 10 sec Period $\pm 0.5^{\circ}\text{F}$ Over a 10 sec Period $\pm 0.0005$ Over a 10 sec Period	$\pm 1$ psf Over a 10 sec Period $\pm 0.5^{\circ}\text{F}$ Over a 10 sec Period $\pm 0.0005$ Over a 10 sec Period	$\pm 1$ psf Over a 10 sec Period $\pm 0.5^{\circ}\text{F}$ Over a 10 sec Period $\pm 0.0005$ Over a 10 sec Period

### LSWT Closed Jet Model Loads

Closed Jet Model Loads	Rear Strut Mount Full Span No Roll	Rear Strut Mount Full Span With Roll	Floor Mount Semispan
Lift Force, lbs	±81,000	±56,000	±112,000
Drag Force, lbs	±18,000	±12,000	±24,000
Side Force, lbs	±7,000	±5,000	±18,000
Pitching Moment, ft-lbs	±41,000	±24,000	±94,000
Rolling Moment, ft-lbs	±37,000	±21,000	±840,000
Yawing Moment, ft-lbs	±19,000	±11,000	±118,000

Note: Loads are for unpowered models referenced to 1/4 mean aerodynamic cord at the plane of symmetry (5 atmospheres)

### LSWT Open Jet Model Loads

Open Jet Model Loads	Rear Strut Mount Full Span No Roll	Rear Strut Mount Full Span With Roll	Floor Mount Semispan
Lift Force, lbs	±16,200	±11,200	±22,400
Drag Force, lbs	±3,600	±2,400	±4,800
Side Force, lbs	±1,400	±1,000	±3,600
Pitching Moment, ft-lbs	±8,200	±4,800	±18,800
Rolling Moment, ft-lbs	±7,400	±4,200	±168,000
Yawing Moment, ft-lbs	±3,800	±2,200	±23,600

Note: Loads are for unpowered models referenced to 1/4 mean aerodynamic cord at the plane of symmetry (1 atmosphere)

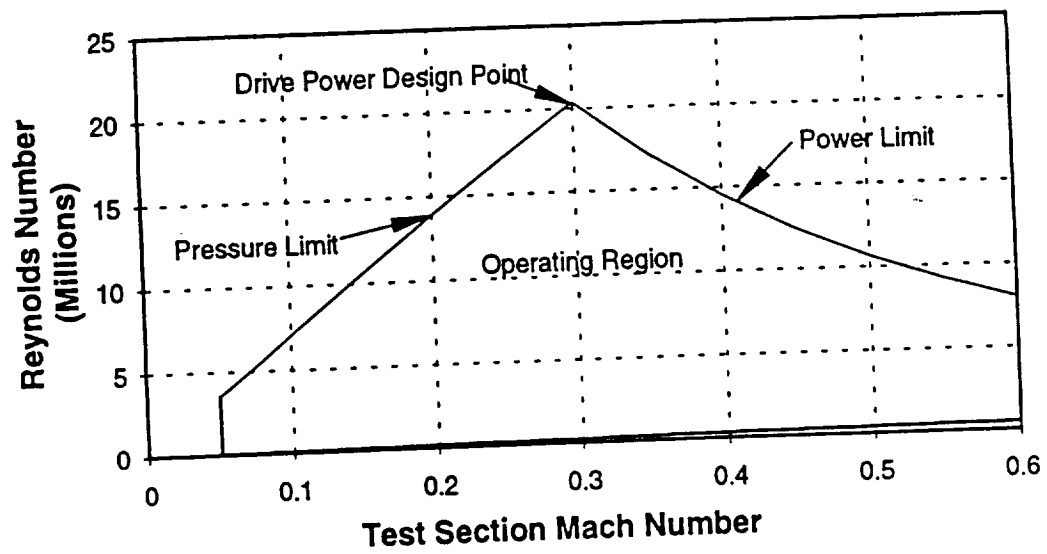
## TSWT Closed Jet Model Loads

Closed Jet Model Loads	Rear Strut Mount Full Span No Roll	Rear Strut Mount Full Span With Roll	Floor Mount Semispan
Lift Force, lbs	±53,520	±26,850	±53,700
Drag Force, lbs	±10,650	±5,400	±10,750
Side Force, lbs	±5,400	±2,250	±10,800
Pitching Moment, ft-lbs	±41,550	±14,850	±59,000
Rolling Moment, ft-lbs	±18,550	±2,250	±221,500
Yawing Moment, ft-lbs	±6,200	±11,000	±88,600

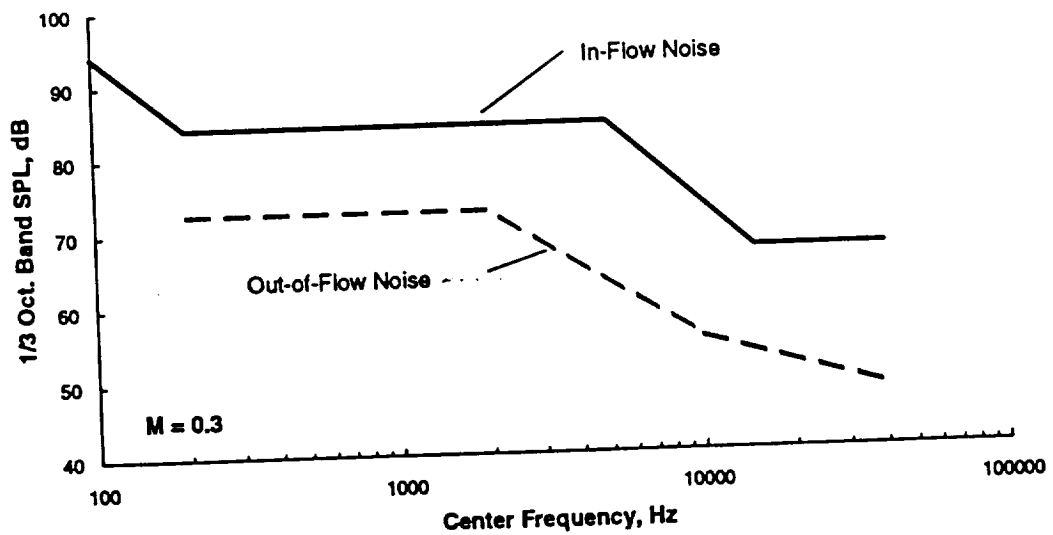
Note: Loads are for unpowered models referenced to 1/4 mean aerodynamic cord at the plane of symmetry (5 atmospheres)

## Auxiliary System Operational Requirements

Item	Requirement	Comments
Tunnel Pressurization Rate	0.1 atmospheres per minute	Pressurizing One Tunnel at a time.
Tunnel Pressurization Rate	0.05 atmospheres per minute	Pressurizing Both Tunnels Simultaneously
Plenum Pressurization Rate	60 Seconds	Recover Plenum from 1 atmosphere condition to either minimum or maximum pressure condition
Tunnel De-Pressurization Rate	40 minutes	Depressurizing One Tunnel at a time.
Low Pressure Air Dewpoint	-60°F at 300 Psig	
Air Filtration	10 Micron Nominal	
Vacuum System Pressure	0.07 atmospheres	
Vacuum System Flowrate	5 lbs. per second	
Low Pressure Air Storage	268,000 cubic feet at 300 psig	
High Pressure Air Storage	7000 cubic feet at 4,500 psig	



**Figure 1: LSWT Performance Envelope**  
(Full Span Model, Reference Length -  $c_{bar} = 2.19$  feet)



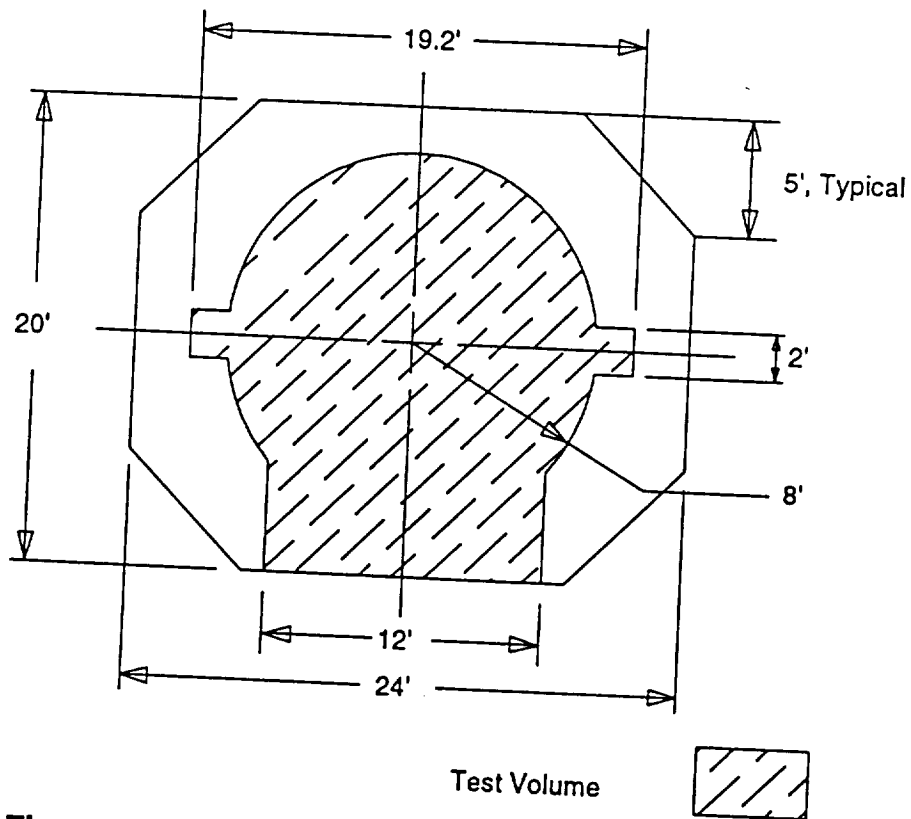
**Figure 2: LSWT Background Noise**

Model Span Determined by  
Assuming it is 80% of the Tunnel Width or Height

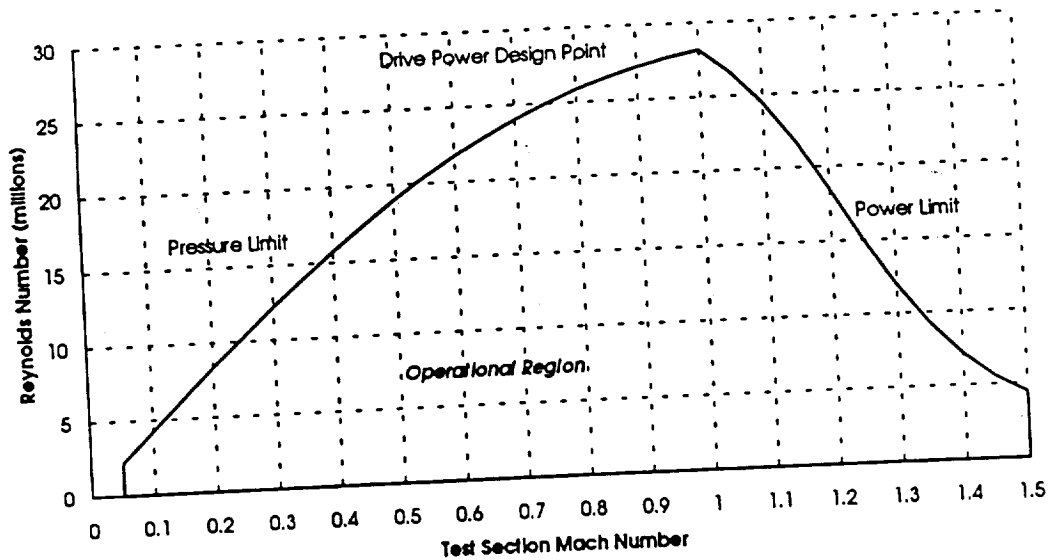
Span =  $0.8 \times 24' = 19.2$  feet  
and =  $0.8 \times 20' = 16$  feet (32 feet for semi-span model)

Fuselage Length =  $\frac{32}{240} \times 200 = 26.7$  feet

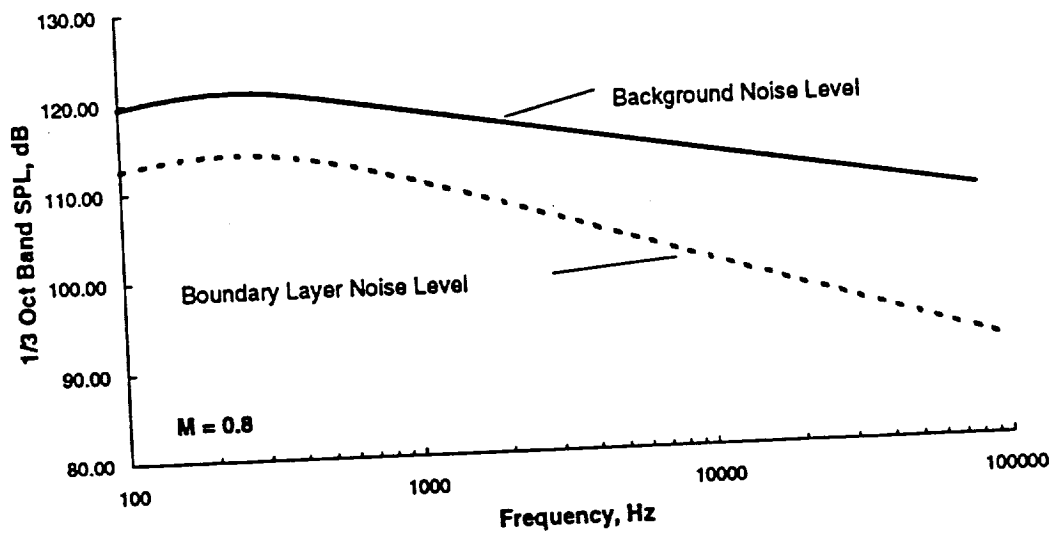
Test Volume Length = 30' - Cylindrical



**Figure 3: LSWT Test Section Volume for Flow Quality**



**Figure 4: TSWT Performance Envelope**  
(Full Span Model, Reference Length -  $c_{bar} = 1.31$  feet)

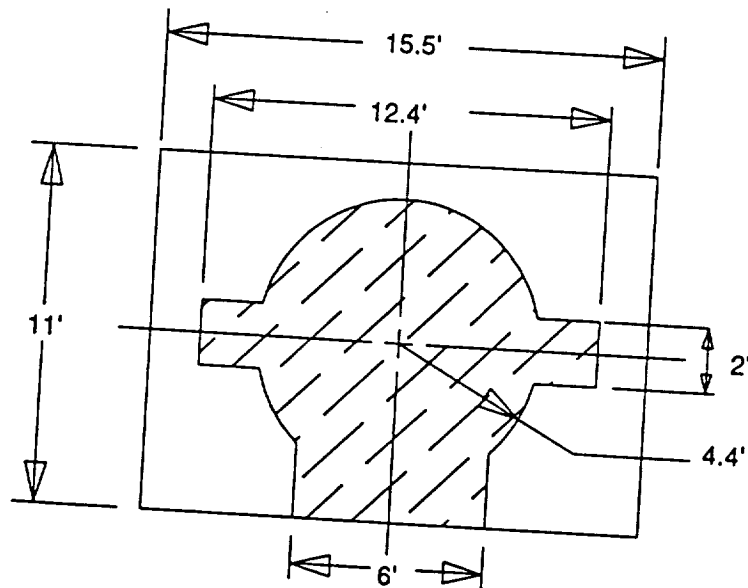


**Figure 5: TSWT Background Noise**

Model Span Determined By:  
Assuming Model Span is 80% of Tunnel Width or Height

Span =  $0.8 \times 15.5' = 12.4$  feet  
and =  $0.8 \times 11' = 8.8$  feet (17.6 feet for semi-span model)

Test Volume Length = 15 feet - Cylindrical



Test Volume

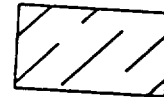


Figure 6: TSWT Test Section Volume for Flow Quality



**ATTACHMENT 2.2**

**NATIONAL WIND TUNNEL COMPLEX**

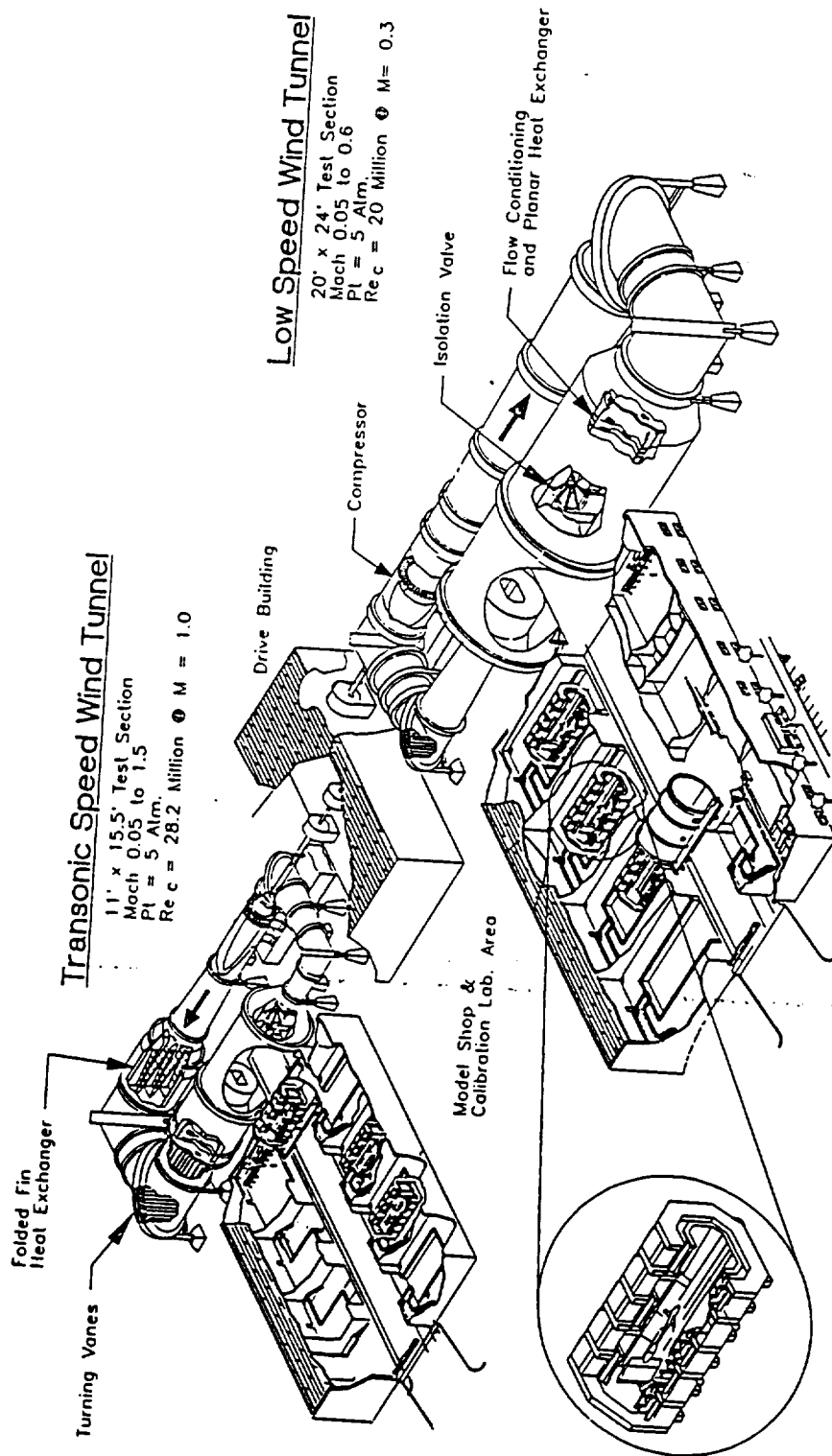
**COST BASELINE**

**TECHNICAL DESCRIPTION**

**CONCEPT D - OPTION 5**



# National Wind Tunnel Complex (Partial Complex)





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## 1000 SITE AND INFRASTRUCTURE

### 1100 SITE PREPARATION

The baseline New Wind Tunnel Complex conceptual design is assumed to be located on a "generic" site, as shown on the accompanying sketch. That is, one that has favorable, but not unrealistic, attributes insofar as design, schedule and cost impacts are concerned. The essential features of the generic site are listed below:

- The site is reasonably level, has good soil conditions, water table is below excavated levels (at least 30 ft deep), the excavations can be sloped 1 to 1, the excavated materials are suitable for structural back-fill and surplus materials can be disposed of locally. No rock excavation is included.
- The site grade is assumed at elevation 100 ft-0 in AMSL. This will be the datum for this report.
- The site is near a four lane highway and within 5 miles from a navigable river or an active railroad spur.
- The local electric utility company will provide two independent 3 phase, 138kV power sources to on-site switchyard termination.
- The telephone company will provide the required telephone and data lines to the site.
- Natural gas supply pipeline is available within one half mile of the site.
- Potable water supply pipeline is available within one half mile of the site.
- Sanitary sewage will be discharged into local utility's existing sanitary sewerage system. Storm drainage systems will discharge to existing drainage systems after separation and treatment of any contaminants.
- No site remedial work that may be required to mitigate environmental concerns is assumed, therefore, no allowance is included for this.

### **1110 Investigation**

The scope includes site surveys, environmental assessment, noise and vibrations surveys, geo-technical investigations and soil investigations, soil borings, preparation of soils reports. Environmental impact statement, archaeological, wetlands and/or any other applicable surveys will be done if the conditions requiring those reports exist.

### **1120 Clearing and Grubbing**

Clearing and grubbing of 50 acres of light brush and vegetation is provided.

### **1130 Demolition**

No demolition is assumed at the generic site.

### **1140 Dewatering**

No permanent plant de-watering system is required at the generic site.

## **1200 SITE IMPROVEMENTS**

The scope includes all excavation, finished grading, drainage, paving, roads, parking lots, associated area lighting, and landscaping within the New Wind Tunnel Complex perimeter. A roadway ensures access to all major tunnel or building areas during phased construction and for continued maintenance duties after the complex is completed.

### **1210 Earthwork**

Cut and fill of 50,000 cubic yards is provided to take site grade to a uniform 100-ft-0 in AMSL. Mass excavation of 312,300 cubic yards is provided as preparation for structural foundations associated with the depressed wind tunnels, utility tunnels and associated buildings. Backfill of 250,000 cubic yards is provided around the wind tunnel foundations and utility tunnels. Maximum depth of cut is 40 ft and average depth of cut is 15 ft.

### **1220 Drainage**

Storm drainage system consisting of catch basins, piping and culverts are provided to collect and direct surface water run-off off-site to a retention pond. Discharge to existing storm sewer system assumed with collection laterals and mains from 50 acres figured at 6300 LF.

### **1230 Roads and Paving**

Using two lane access road (5450 LF) from existing roadway. Site perimeter roads, parking areas and concrete walkways (15,500 SY) are also provided. Temporary roads are used during construction.

### **1240 Railway**

No railway connection is included in generic site.

### **1250 Waterway**

Delivery of major equipment modules (100 to 200 tons) to the generic site is assumed to be by barge. A 200 ft x 50 ft barge unloading wharf is provided, along with 1,500 LF (10' wide) of river bank shore protection (rip-rap).

### **1260 Landscaping**

Minimal landscaping treatment is provided. Native trees, grasses and shrubs are preserved, where safety, operability and aesthetic considerations warrant.

### **1270 Fencing and Gates**

Fencing: 3,500 ft around specific equipment locations, single 8 ft high chain link security fencing and 7,200 ft site perimeter, single 8 ft high chain link security fence.

Gates: Pedestrian access gates in various locations for interior fencing and five, two-way standard truck/car gate (16 ft wide x 8 ft high).

Security: A security system is installed around the outside perimeter of the perimeter fence.

## **1300 UTILITY SUPPLY AND DISTRIBUTION SYSTEM**

### **1310 Central Heat Pump System**

This WBS has been deleted. The cost of the heating systems are included with the cost of the buildings.

### **1320 Central HVAC Chiller System**

This WBS has been deleted. The cost of the HVAC systems are included with the cost of the buildings.

### **1330 Water Supply and Treatment System**

Depending upon the site selected, two alternatives have been identified for providing cooling tower makeup water and potable water.

The first alternative for the cooling tower makeup water is to use a river intake and treatment system as the water source. The intake structure for this alternative includes trash-rack and debris screens. A 24 inch pipe is required to distribute water from the intake structure to the cooling towers. Two pumps with a maximum pumping rate of 10,000 gpm are required. For the purpose of this report, the distance from the river to the cooling towers is estimated to be 1000 feet. The second alternative for the cooling tower makeup water is to use a municipal water source. The municipal water source will require pumps approximately equal in capacity to the river water makeup source.

The first alternative for the potable water is to use well water as the source of potable water. Multiple wells with a basic filtering and chlorination treatment system, 100,000 gallon storage tank, and 100 gpm pumps are required. The second alternative for the potable water is to use a municipal water source and a 100,000 gallon storage tank. Depending upon the pressure available from the municipal water source, pumps may be needed.

The potable water system piping is estimated to be 5000 feet long.

The anticipated plot size for the tank and pumps is 6000 square feet.

### **1340 Sanitary Waste Water Collection and Treatment System**

Depending upon the site selected, two alternatives have been identified for providing sanitary waste water collection and treatment.

For the generic site, sanitary waste will be collected and transferred to two 200 gpm sewage lift pumps. Waste will be treated by a 20,000 gallon per day treatment system prior to discharge. Sewage collection piping is estimated to be 4000 feet long.

If the site selected has a regional or local sewage treatment facility of sufficient capacity, the sewage will be collected and pumped to this existing facility for treatment and discharge.

The anticipated plot size is 2000 square feet.

### **1350 Natural Gas System**

A natural gas pipeline is assumed to be available within 2,000 feet of the site. For

the generic site, 2,000 feet of piping is provided from the natural gas pipeline to the site, along with a pressure reducing station and 4,000 feet of on-site distribution piping. Once the site selection is finalized, negotiations can proceed to determine if the natural gas utility company will provide the piping to the site and will provide the metering and pressure reducing station. Maximum natural gas demand is 3000 scfm. Projected annual usage is between 100 and 200 mcf.

#### **1360 Yard Fire Protection System**

Water for fire protection at the generic site will be provided from the cooling tower basins using both electric motor driven and diesel engine driven pumps. A looped non-potable fire main will supply water to the buildings for wet pipe and dry pipe systems. Approximate 20 water hydrants will be installed throughout the site. It is assumed that mobile fire protection will be provided from local municipal fire stations.

Two electric motor driven pumps of 2,000 gpm and one diesel engine driven pump of 2,000 gpm will be required. The fire water main piping is estimated to be 6,000 feet long.

The anticipated plot size is 2000 square feet.

#### **1370 Compressed Air System**

A 200 scfm, 90 psi compressed air system will be provided for shop service air usage throughout the site. It is estimated that 4,000 feet of distribution piping will be needed to distribute service air to the various facilities. Individual compressor modules will also be provided at strategic locations.

#### **1380 Steam System**

No steam system has been included for the generic site. During preliminary and/or final design, engineering analysis will be conducted to determine if the use of a central steam distribution system is a viable option for heating of the buildings and for process air heating.

### **1400 YARD ELECTRICAL POWER SYSTEM**

#### **1410 Electrical Equipment**

The electrical substation and power distribution system includes the yard distribution system and related switching, power conditioning, harmonic filtering, and voltage transforming equipment. Depending upon voltage available from the electrical utility company, the delivered primary voltage will range from 115 kV to 230 kV. For the generic site, 138 kV has been chosen as the delivered primary

voltage. After site selection is made, negotiations will be held with the utility company to determine the exact voltage that will be delivered. It is anticipated that the 138 kV power will be delivered to one main substation and two wind tunnel drive substations (one substation each for the Low Speed Wind Tunnel and the Transonic Wind Tunnel). Medium and low voltage substations will provide power at 4.16 kV and 480 volts. Power will be distributed between the substations and equipment by power cables/busses in cable tunnels and ductbanks.

Estimated power levels are:

**Table 1410.1 NWTC Site Power Requirements**

Parameter	Requirement
Total connected load	590 MW
Peak demand load	500 MW
Average monthly electrical energy usage	55 million KWH
Average monthly power factor	95%
Voltage at interconnect with utility company	138 kV
Voltages at interconnect with site substation network	138 kV and 13.8 kV
Short circuit capacity	10,000 MVA
Ramp rate	2 MW per second

The substations will be strategically located in separate areas to keep the secondary cable/bus systems to a minimum. Security lighting and security fences will be provided. Estimated plot sizes are:

- Main substation: 220 feet by 330 feet.
- Transonic Wind Tunnel Substation: 320 feet by 150.
- Low Speed Wind Tunnel Substation: 160 feet by 150 feet.

#### **1420 Electrical Material**

Electrical material includes the cable, conduit, and cable tray required for control, protection, and metering.

#### **1500 OTHER ELECTRICAL SYSTEMS**

##### **1510 Lighting Systems**

General area lighting, not including security fence lighting (WBS 1530), is included. Lighting for all outside support systems requiring 24

hour maintenance and/or operation will have enhanced illumination levels. In areas where safety and/or security are important, the lighting will be supplied by an uninterruptible power source or will automatically transfer to a diesel powered generator. The system is estimated to include twelve 100 ft high light towers with 5000 watt flood lights and fed by 4000 feet of direct buried cable with transformers, panelboards, and switchgear.

#### **1520 Communications Systems**

Telephones and intercoms will be provided throughout the facilities. In yard and facility areas where safety, security, or efficiency of the operation may be improved, remote video/audio capability will be employed.

#### **1530 Security Systems**

Security systems including fencing, gates, security lighting, remote operated close circuit television (CCTV), alarms, and separate security communications will be provided for the complex. Security lighting will include approximately twenty 30 ft high light towers with 500 watt lights and will be fed from approximately 6,000 feet of direct buried cable with transformers, panelboards, and switchgear. Security intrusion alarms will be provided at the main gates and at personnel gates.

#### **1540 Grounding**

An electrical grounding system will be provided to meet the National Electric Code, local codes, and utility company requirements.

#### **1550 Cathodic Protection**

A cathodic protection system will be provided to reduce the corrosion of electrical components and equipment.

#### **1550 Lightning Protection**

A protection system will be provided to protect the electrical equipment from lightning strikes.

#### **1570 Freeze Protection**

Heat tape, heaters, and controls will be provided to prevent freezing of exterior water filled lines.

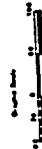
#### **1580 Environmental Monitoring (weather)**

Although the type of environmental monitoring required has not been defined, a

cost allowance is included for a station to monitor weather, noise, emissions, effluents, or similar environmental factors for the generic site.

**1590 DC Power for Instrumentation**

A DC power supply will be provided for the instrumentation systems.



**Figure 1000.a Site Arrangement**

## 2000 BUILDINGS

### 2100 TEST PREPARATION/CONTROL BUILDINGS

#### 2110 Low Speed Wind Tunnel Test Preparation/Control Building

##### General

The Low Speed Wind Tunnel Test Preparation Building is a massive, single story structure with six cart rooms, and control and computer rooms. There is direct access to a limited capability model shop and test equipment storage warehouse through a cross-track system running through the center of the building. All tracks are heavy-duty (136 lbs/yd), flat-top crane type. An interconnected underhung overhead crane system is provided in all eight cart rooms and in the operating gallery and most areas of the shop. Crane-moved bridges permit personnel and small cart/dolly access across rail slots in the operating floor at a 112 ft elevation level which is also the test section floor level in all tunnels, while stairs permit personnel access across the shuttle car rail pit. Dolly/air bearing access is gained by driving over the top of one of the two prepositioned shuttle cars to span the rail pit.

Access for personnel and equipment into the wind tunnels is through the pressure doors on the access tubes of the tunnel pressure shell. Model and test cart access into the building at opposite ends is provided by rails through the Model Shop/Warehouse. The building is configured and sized to accommodate all wind tunnel design features equipment. A large interconnected perimeter corridor is provided in the building at EI 100 and at EI 112.

The control and computer areas are adjacent to the Low Speed Tunnel Enclosure Building. The control room has raised flooring and houses computer-driven control and data acquisition systems.

Two of the cart rooms will be large enough to accommodate any plenum section from the tunnel. The other four cart rooms provide floor space for a simulated sting mount at the end of the flush inset rail cart tracks. They also have the capability to pretest an entire test section with model on its sting or on its external balance mount. Each room is complete with all necessary calibration equipment for all balances and mounts. There is a remote test checkout control panel for conducting full pretest simulation of automated test sequencing located in a TEMPEST protected room inside each cart room.

### Building Construction

The building is a custom-engineered, heavy braced, steel framed structure with insulated steel panel siding, overhead and safety lighting. Additional sealing and insulation are provided to eliminate infiltration of outside air. The foundation is a reinforced concrete mat with depressions to accommodate the rail and cart system. Truss roof structure supports roof loads.

### Dimensions

The external size is 355 ft wide x 302 ft long x 90 ft high (above local grade). Four of the cart rooms measure 87 ft long by 55 ft wide and can accommodate test carts/test sections measuring 75 ft long by 30 ft wide by 36 ft high. The other two cart rooms measure 87 ft long by 75 ft wide and can accommodate tunnel plenums measuring 60 ft high.

### HVAC

Heating, ventilation, and air conditioning is provided throughout the building. HVAC systems will be controlled to provide a slight positive pressure in the building to eliminate infiltration of unconditioned air.

### Fire Protection

Protection is provided by automatic dry pipe sprinkler fire suppression system. There are hose cabinets near main access doors. A fire alarm panel tied to the fire station is provided. Smoke detectors and pull stations are tied into this panel.

### Tunnel Control/Computer Rooms

The control and computer rooms have raised computer room floors, located next to the tunnel enclosure. TEMPEST provisions are incorporated into each room. The control room is 40 ft wide x 40 ft long x 10 ft high. The computer room is 45 ft wide x 40 ft long x 10 ft high.

### Test Simulation Control/Computer Rooms

Six rooms with raised computer room floors are provided, each room located on the second level in the perimeter access corridor adjacent to the corresponding cart room. TEMPEST provisions are incorporated into each of these rooms.

### Cart Rooms

Four model build-up areas are provided with floor size inside closed doors sufficient to accommodate model carts and two model build-up areas with floor size

inside closed doors sufficient to accommodate an entire test plenum section. Work platforms are provided in each room to provide access to the model cart. TEMPEST security compartmentalization requirements are incorporated into each of these rooms.

The two inside end cart rooms are also equipped for continuous flow high pressure air for model engine simulation. Each room is provided with an exhaust connection to a roof mounted muffler tower. Over pressure blow-out provisions for each room are incorporated. Only one of these rooms can utilize the high pressure air capability at a time.

#### Cranes

An underhanging interlocking bridge crane system consisting of 35 ton hoist/70 ton bridge units is provided. The crane system services the eight separate cart rooms and connects with parking spaces, model shop and storage warehouse. Crane trolleys with hanging loads are capable of moving through open vertical sliding doors across interconnecting bridges.

#### Elevators

Two 20 ft x 25 ft hydraulic freight/passenger elevators are provided to service the mezzanine level of the test preparation bays.

#### Security

TEMPEST physical and EMI security is provided in the tunnel and simulation control rooms, the eight cart room envelopes, and the transfer corridor to the end of the air lock at the tunnel access pressure door face. Overhead segmented doors or sliding doors provide access for test carts/test sections and plenum sections between the cart rooms and the transfer corridor. Cardkey access and intrusion alarm systems for each of the cart rooms and video monitoring of the transfer corridor is provided.

### **2120 Transonic Wind Tunnel Test Preparation/Control Building**

#### General

The Transonic Wind Tunnel Test Preparation Building is a massive, single story structure with four cart rooms and control and computer rooms. There is direct access to a limited capability model shop and test equipment storage warehouse through a cross-track system running through the center of the building. All tracks are heavy-duty (136 lbs/yd), flat-top crane type. An interconnected underhung overhead crane system is provided in all eight cart rooms and in the operating gallery and most areas of the shop. Crane-moved bridges permit personnel and

small cart/dolly access across rail slots in the operating floor at a 112 ft elevation level which is also the test section floor level in all tunnels, while stairs permit personnel access across the shuttle car rail pit. Dolly/air bearing access is gained by driving over the top of one of the two prepositioned shuttle cars to span the rail pit.

Access for personnel and equipment into the wind tunnels is through the pressure doors on the access tubes of the tunnel pressure shell. Model and test cart access into the building at opposite ends is provided by rails through the Model Shop/Warehouse. The building is configured and sized to accommodate all wind tunnel design features equipment. A large interconnected perimeter corridor is provided in the building at El 100 and at El 112.

The control and computer areas are adjacent to the Transonic Tunnel Enclosure Building. The control room has raised flooring and houses computer-driven control and data acquisition systems.

The cart rooms provide floor space for a simulated sting mount at the end of the flush inset rail cart tracks. They also have the capability to pretest an entire test section with model on its sting or on its external balance mount. Each room is complete with all necessary calibration equipment for all balances and mounts. There is a remote test checkout control panel for conducting full pretest simulation of automated test sequencing located in a TEMPEST protected room inside each cart room.

### Building Construction

The building is a custom-engineered, heavy braced, steel framed structure with insulated steel panel siding, overhead and safety lighting. The foundation is a reinforced concrete mat with depressions to accommodate the rail and cart system. Truss roof structure supports roof loads.

### Dimensions

The external size is 340 ft wide x 180 ft long x 65 ft high (above local grade). The cart rooms measure 80 ft long by 55 ft wide and can accommodate test carts/test sections measuring 68 ft long by 30 ft wide by 36 ft high.

### HVAC

Heating, ventilation, and air conditioning is provided throughout the building.

### Fire Protection

Protection is provided by automatic dry pipe sprinkler fire suppression system.

There are hose cabinets near main access doors. A fire alarm panel tied to the fire station is provided. Smoke detectors and pull stations are tied into this panel.

#### Tunnel Control/Computer Rooms

The control and computer rooms have raised computer room floors, located next to the tunnel enclosure. TEMPEST provisions are incorporated into each room. The control room is 40 ft wide x 40 ft long x 10 ft high. The computer room is 45 ft wide x 40 ft long x 10 ft high.

#### Test Simulation Control/Computer Rooms

Four rooms with raised computer room floors are provided, each room located on the second level in the perimeter access corridor adjacent to the corresponding cart room. TEMPEST provisions are incorporated into each of these rooms.

#### Cart Rooms

The model build-up areas are provided with floor size inside closed doors sufficient to accommodate model carts. Work platforms are provided in each room to provide access to the model cart. TEMPEST security compartmentalization requirements are incorporated into each of these rooms.

The two inside end cart rooms are also equipped for continuous flow high pressure air for model engine simulation. Each room is provided with an exhaust connection to a roof mounted muffler tower. Over pressure blow-out provisions for each room are incorporated. Only one of these rooms can utilize the high pressure air capability at a time.

#### Cranes

An underhanging interlocking bridge crane system consisting of 35 ton hoist/70 ton bridge units is provided. The crane system services the four separate cart rooms and connects with parking spaces, model shop and storage warehouse. Crane trolleys with hanging loads are capable of moving through open vertical sliding doors across interconnecting bridges.

#### Elevators

One 20 ft x 25 ft hydraulic freight/passenger elevator is provided to service the mezzanine level of the test preparation bays.

#### Security

TEMPEST physical and EMI security is provided in the tunnel and simulation

control rooms, the four cart room envelopes, and the transfer corridor to the end of the air lock at the tunnel access pressure door face. Overhead segmented doors or sliding doors provide access for test carts/test sections and plenum sections between the cart rooms and the transfer corridor. Cardkey access and intrusion alarm systems for each of the cart rooms and video monitoring of the transfer corridor is provided.

## **2200 WIND TUNNEL DRIVE BUILDING**

### **2210 LSWT/TSWT Drive Building**

This building houses the drive systems for both tunnels including the drive motor for the Low Speed Wind Tunnel and the drive motors for the Transonic Wind Tunnel. The building also houses all of the associated variable speed motor controls, couplings, lubrication, and cooling systems for each drive system. Cooling ductwork, storage and maintenance space is provided under each pedestal. Drive controls, power supply and conditioning system and motor cooling (air to water heat exchangers) system are located outdoors adjacent to drive building.

#### Building Construction

This is a custom-engineered, heavy braced steel framed structure with insulated steel panel siding, overhead and safety lighting. The building foundation consists of a reinforced concrete basemat keyed into the soil strata and a raised pedestal to support the drive system. Each foundation is isolated from the other. Each foundation is common to the corresponding isolated compressor foundation to prevent differential movement between the drive systems and the compressors.

#### Dimensions

The external size is 125 ft wide x 280 ft long x 60 ft high. The motors are mounted on raised pedestals.

#### HVAC

Heating and ventilation is provided for the building.

#### Fire Protection

Protection is provided by automatic dry pipe sprinkler fire suppression system. There are hose cabinets near main access doors. A fire alarm panel tied to the fire station is provided. Smoke detectors and pull stations are tied into this panel.

### Cranes

An overhead bridge crane, 300 ton capacity, services the all of the equipment and laydown space.

## **2300 SUPPORT BUILDINGS**

### **2310 Model Shop and Warehouse**

The Model Shop is a single story heavy duty structure interconnected with the Low Speed Wind Tunnel Test Preparation/Control Building and the Transonic Wind Tunnel Test Preparation/Control Building. The building houses the main machine shop including a few heavy and light machine tools and assembly areas for fixing test models and test equipment, air calibration shop, balance calibration shop, electronics shop, and a vertical stacking test storage warehouse. The warehouse is accessed from the exterior through a large access door in laydown area in the shop. There is an internal office tower over the shop area on levels 2, 3, 4 and 5 which has additional floor space for shop and test engineering, photo lab, medical room, administration, conference rooms, planning rooms, rest rooms and customer areas.

The shop is split into two working areas and connects with a matching corridor from the LSWT test prep/control buildings to the TSWT test prep/control building. This central corridor permits transport of test carts/test sections and/or test models from either of the tunnels/cart rooms into the shop for setup or rework and maintenance. On one side of the corridor is a laydown high bay area next to the machine shop and an equipment storage area. On the other side of the corridor is a walled off vertical stacking warehouse with a semi-automated stacking crane. The module/rack size is adjustable to fit whatever storage requirements exist within the total volume set and the aisleway configuration selected. Covered and locked pallets are used to store models and test accessories.

The other half of the shop consists of model and test setup/fixtures fabrication and repair equipment and work areas. Also on this side are the air calibration shop, balance calibration shop, and the electronics shop. An internal office tower is located next to the elevators between the shop and the test prep/control building and extends 5 stories high above the ground floor.

### Building Construction

The building is a custom-engineered steel-framed structure with insulated steel panel siding, overhead and safety lighting, located on a separate three foot thick, concrete mat foundation. There is a 30 ft x 60 ft x 10 ft thick isolated foundation in the balance calibration area, capable of resisting balance loads.

### Dimensions

The building is 302 ft wide x 335 ft long x 65 ft high. The central portion of the main floor is at El 100. Warehouse contains cubicles of three sizes: 160 - 10 ft x 10 ft x 7.5 ft, 114 - 10 ft x 5 ft x 5 ft and 570 - 5 ft x 5 ft x 5 ft. The internal office tower has additional floor space on levels 2, 3, 4 and 5 and offers 28,000 ft<sup>2</sup> of office type space for the other functional areas.

### HVAC

Heating, ventilation, and air conditioning is provided throughout the building.

### Fire Protection

Protection is provided by automatic dry pipe sprinkler fire suppression system. There are hose cabinets near main access doors. A fire alarm panel tied to the fire station is provided. Smoke detectors and pull stations are tied into this panel.

### Cranes

There are a number of underhung interconnected bridge cranes with capability of moving full hanging load throughout high bay shop area to any point inside connected test prep/control building including through open sliding doors.

### Elevators

Two 20 ft x 25 ft hydraulic combination personnel and freight/maintenance elevators are at either end of this building connecting with the Shop/Office/Test Preparation Buildings. One elevator serves the first 2 floors and the other serves all 5 floors and roof of building for maintenance of HVAC units and vertical door-hoist house equipment.

### Planning area

There is space for numeric control programming and shop planners provided on the second floor level in the office tower.

### Office, Administrative, Conference, and Customer Areas

These areas are on the upper floors above the shop area.

### Photo Laboratory

This area houses photographic development equipment and processes all site photographic data. There are provisions for TEMPEST shielded and secure

operations and storage.

#### Air Calibration

This area contains airflow measuring equipment and static thrust facility. The facility includes exhaust muffler tower on roof. There is an source of high pressure air at 250 lb/sec, 3000 psi, and 700 degrees F at point of use plus a source of vacuum.

#### Balance Calibration

This area houses equipment for calibrating external and internal balances for site and has easy access to the cart rooms.

#### Flutter Calibration

This area houses equipment for calibration of flutter models in portion of support shop located next to balance and air calibration labs. There is easy access to the cart rooms of both model/prep buildings.

#### Electronics Shop

An electronics shop area is provided to support those needs of the LSWT and TSWT.

### **2330 Engineering Office**

This two story building provides engineering and administrative offices to partially serve the personnel supporting the operation of the wind tunnels. The remainder of the facility office space is located in the model shop/warehouse. Included in the office area are planning rooms, tele-conference rooms, and customer areas. Also included in this building is a cafeteria and food kitchen.

#### Building Construction

This is a custom-engineered steel framed structure with insulated steel panel siding. The foundation consists of spread footings and grade beams, with a slab on grade.

#### Dimensions

The building is 115 ft wide x 115 ft long = 13,225 ft<sup>2</sup> per story, 26,450 ft<sup>2</sup> total.

### HVAC

Heating, ventilation, and air conditioning is provided throughout the building.

### Fire Protection

Protection is provided by automatic wet pipe sprinkler fire suppression system. There are hose cabinets near main access doors. A fire alarm panel tied to the fire station is provided. Smoke detectors and pull stations are tied into this panel.

### **2340 Guard House**

This building houses security personnel and supports associated security functions.

### Building Construction

This is a pre-engineered steel building on slab foundation with insulated steel panel siding.

### Dimensions

The guard house is 40 ft wide x 40 ft long x 10 ft high

### HVAC

Heating, ventilation, and air conditioning is provided for the building.

### Fire Protection

Protection is provided by automatic wet pipe sprinkler fire suppression system. There is a hose cabinet near the main access door. A fire alarm panel tied to the fire station is provided. Smoke detectors and pull stations are tied into this panel.

### **2350 Outfitting**

This category includes items necessary during activation and operation of the New Wind Tunnel Facility. These items include vehicles and other equipment, shop equipment and other hand tools, diagnostic and testing equipment, furniture, personal computers and software, and telephones and switching equipment. Machine tools in shop shall include lathes, mills, drill presses, various hand tools, presses, welding machines and other miscellaneous tools.

## **2400 UTILITY BUILDINGS**

### **2410 Wind Tunnel Pressurization/Vacuum System Equipment Building**

This building houses the wind tunnel air pressurization and vacuum system compressors, motors, and associated electrical, control and lubrication equipment. Cooling system heat exchangers are located in the basement. A prefabricated modular control room is located on the first floor.

#### Building Construction

This is a pre-engineered steel building with insulated steel panel siding and overhead and safety lighting. Foundation consists reinforced concrete elevated slab for the first floor supported by concrete columns. The basement floor consists of a reinforced concrete mat. The basement is required to provide space to run process piping and provide a location for compressor ancillary equipment. Access for large equipment is provided by large rollup doors.

#### Dimensions

The building is 55 ft wide x 390 ft long x 35 ft high above grade with a basement.

#### HVAC

Heating and ventilation are provided.

#### Fire Protection

A wet pipe sprinkler system is provided. A fire alarm panel tied to the fire station is provided. Smoke detectors and pull stations are tied into this panel.

### **2420 Heavy Gas Handling Equipment Building**

This item was deleted from this concept.

### **2430 Heat Pump System Equipment Building**

This item was deleted from this concept.

### **2440 HVAC Chiller System Equipment Building**

This item was deleted from this concept.

## **2450 Utility Tunnels**

Utility tunnels are provided to allow below grade piping and electrical commodities routing between major facilities such as the two wind tunnels, drive buildings, and test/assembly building, and the associated support facilities such as the electrical substations, air pressurization /vacuum equipments, cooling towers, etc.

### Dimensions

The tunnels are 10 ft high x 15 ft wide, 6,300 ft long configured to fit site with looped mains and laterals.

### HVAC

Heating is not provided. Natural ventilation will be provided.

### Construction

Construction is one foot thick, reinforced concrete, with maintenance lighting.

## **2460 Other Minor Buildings**

### Compressor Blade Shop

This is a pre-engineered steel building with insulated steel panel siding and overhead and safety lighting. Foundation consists of reinforced concrete slab on grade with thickened areas under walls and columns. The building is 40 ft wide x 50 ft long x 15 ft high. Heating and ventilation are provided.

### **3000 AUXILIARY PROCESS SYSTEMS**

#### **3100 TEST MODEL AND CART TRANSPORT**

##### **3110 Low Speed/Transonic Wind Tunnel Shuttle Carts**

The Preparation Hall Shuttle Cart for the LSWT has been moved to WBS 4580.

The Preparation Hall Shuttle Cart for the TSWT has been moved to WBS 5540.

##### **3120 Test Cart/Section Elevators**

This element has been moved to 3110.

#### **3200 WIND TUNNEL PRESSURIZATION/VACUUM SYSTEM**

The wind tunnel pressurization/vacuum system is a multi-purpose grouping of systems that support all operations associated with the LSWT and the TSWT. The system is an energy efficient interconnected system that allows for multi-tasking of components in order to reduce the overall complexity of the system while meeting the productivity requirements. The system is composed of three primary subsystems: (1) the tunnel/plenum pressurization system, (2) the model propulsion air system, and (3) the tunnel/plenum vacuum system. The performance and productivity requirements for these subsystems are listed below.

The Tunnel/Plenum pressurization system is used to rapidly pressurize the tunnel shell to 5 atmospheres. In addition, the system is used to pressurize the plenum to 5 atmospheres after a model change has been accomplished. The low pressure air system is also used for one of the model propulsion simulations. The performance requirements for this system are:

**Table 3200.1 Low Pressure Air System Operational Requirements**

Item	Requirement
1.	provide sufficient flow and storage capacity to simultaneously pressurize the LSWT shell or the TSWT shell from 1 atmosphere to 5 atmospheres within 40 minutes (at a rate of 0.1 atmospheres per minute).
2.	provide sufficient flow and storage capacity to pressurize the plenum from ambient pressure to 5 atmospheres within 60 seconds, with an average test section entry frequency of three times per hour for each tunnel (6 times per hour). The system is composed of a 300 psig high volume flow compressor system with an air dryer, filtration, and 300 psig storage vessels.
3.	provide sufficient flow and storage capacity to provide the High Speed Civil Transport Nozzle Requirements - total flow of 80 lbm per second at a delivered pressure of 150 psia for a continuous time.

The model propulsion air system is used to provide high pressure air to simulate the propulsive thrust of a jet engine. The requirements vary from unheated air to heated air. The model simulations include Turbine Powered Simulators (TPS) and Ultra-High Bypass Propulsion Simulators (UPS). The performance requirements for this system are:

**Table 3200.2 High Pressure Air System Operational Requirements**

Item	Requirement
1.	Provide sufficient flow and storage capacity to meet the TPS requirements - 35 pounds per second of air at a delivered pressure of 3000 psig and temperature of 400°F for a continuous flowrate.
2.	Provide sufficient flow and storage capacity to meet the UPS requirements - 30 pounds per second of air at a delivered pressure of 300 psig and temperature of 400°F for a continuous flowrate.
3.	The model propulsion system should consider a nominal storage pressure in the range of 4500 psig. (higher pressures to be compatible with the available range of 2500 # class components may be considered).

The model propulsion air system is described in this category only for the compressors, high pressure air dryer, and high pressure air storage. All distribution piping, valves, and model propulsion air heaters are described in WBS element 3620.

The vacuum system is composed of two separate elements. The first category is to provide for rapid evacuation of the tunnel and plenum to a low pressure. This is accomplished using the 300 psig compressor system. The compressor suction is used to reduce the tunnel pressure. The final reduction in pressure and also the vacuum control (i. e., trimming) is accomplished by dedicated low flow vacuum pumps. The vacuum requirements are:

**Table 3000.3 Vacuum System Operational Requirements**

Item	Requirement
1.	Provide sufficient flow and capacity to evacuate the LSWT shell to 0.07 atmospheres (1 psia) in 40 minutes.
2.	Provide sufficient flow and capacity to evacuate the LSWT shell to 0.07 atmospheres (1 psia) in 40 minutes.
3.	Provide sufficient flow and capacity to evacuate the TSWT shell to 0.25 atmospheres (3.7 psia) in 30 minutes, or to 0.5 atmospheres (7.35 psia) in 20 minutes.
4.	Provide sufficient flow and capacity to evacuate the plenum in either the TSWT or the LSWT to the pressure levels specified in 3 to 5 minutes.
5.	Provide capability of tunnel pressure trim (i. e., low flow).

These systems include electric motors and controls, heaters, filters, dryers, storage tanks, as well as piping and valves from the central system throughout the individual wind tunnel subsystems.

Plot size-Unknown at this time.

### **3210 Compressors**

The pressurization system is configured as a two pressure level system with compression and storage capacity at each level. The low pressure system will provide a pressure of 300 psig while the high pressure system will provide a pressure of 4500 psig.

In order to meet the pressurization requirements for the tunnel shells, sufficient storage could not be economically provided. Therefore, the pressurization rate will be provided by direct pumping from the low pressure compressor plant. The tunnel pressurization requirements result in a total flow rate requirement of 460 pounds per second. This flow rate is provided by five, three-stage centrifugal flow compressors operating in parallel, each capable of producing 92 pounds per second. Each compressor utilizes inter-stage cooling to improve efficiency and to reduce the overall thermal loading on the machinery. An aftercooler is also provided for each compressor. The system includes the inlet air filter, and all associated valving for isolation as well as for the pressure control, pressure

bypass, and inter-stage unloading. The compressor train is terminated by a separator to remove the entrained liquid water prior to entering the distribution system to the coalescing filters and dryer package. The overall motor requirement for each compressor is approximately 25,000 horsepower. The motor is a totally enclosed water cooled motor. An air to water heat exchanger with blowers is provided with the motor to remove the heat associated with the motor inefficiencies. The system includes the motor, the motor starter, and the associated switchgear. All controls and interlocks for a complete system are included. The lubrication system, shaft bearings, pedestal bearings, shaft couplings are also included. It is unknown at this time if a reduction gear will be required. However, if a reduction gear is required, then it will be provided with the compressor by the manufacturer.

The model propulsion air requirements are met by a combination of stored air and on-line compressor capability. Due to the frequency of the proposed test program, sufficient air storage to meet the test demands and keep a small compressor system could not be economically provided. Therefore, the flow rate will be provided by a combination of stored air and continuous direct pumping from the high pressure compressor plant. The high pressure air requirements are such that a compressor rate of 140 pounds per second is sufficient to meet the specified demand. The demand will be met with two compressors operating in parallel, each capable of 70 pounds per second. The high pressure compressors will utilize the low pressure compressors as a preliminary staging device. In other words, to provide the model propulsion air required, two of the low pressure compressors are required to be on-line and pumping to feed the high pressure compressors. The high pressure compressors are a combination of centrifugal low stages and axial high pressure stages, for a total of three stages. Each compressor utilizes inter-stage cooling to improve efficiency and to reduce the overall thermal loading on the machinery. An aftercooler is also provided. The system includes all associated valving for isolation as well as for the pressure control, pressure bypass, and for inter-stage unloading. The compressor train is terminated at the discharge flange of the aftercooler. A high pressure air dryer is used to provide a dew point of -60°F at the system design pressure of 4500 psig. The air is then pumped into the high pressure distribution and storage network. The overall motor requirement for each compressor is approximately 25,000 horsepower. The motor is a totally enclosed water cooled motor. An air to water heat exchanger with blowers is provided with the motor to remove the heat associated with the motor inefficiencies. The system includes the motor, the motor starter, and the associated switchgear. All controls and interlocks for a complete system are included. The lubrication system, shaft bearings, pedestal bearings, shaft couplings are also included.

The compressor system is designed to supply on demand and participate in facility load leveling and main drive system soft start intelligent control.

Significant Interfaces: The low pressure compressor system interfaces are: (1) WBS 1400 by the electrical power connections to the switchgear, (2) WBS 7200 for controls and instrumentation, (3) WBS 3250 for the air system connections which are at the upstream flange of the suction isolation valve, at the manifold discharge valve for the inter-stage pressure relief valves and inter-stage unloading valves, and the downstream flange of the separator isolation valve, (4) WBS 2410 at the foundation, anchor bolt point for the foundations for the compressors, (5) and at the flange connections at the main cooling water distribution header where the cooling water is piped to the individual compressors. The high pressure compressor system interfaces are: (1) WBS 1400 by the electrical power connections to the switchgear, (2) WBS 7200 for controls and instrumentation, (3) WBS 3250 for the air system connections which are at the upstream flange of the suction isolation valve, at the manifold discharge valve for the inter-stage pressure relief valves and inter-stage unloading valves, and the downstream flange of the compressor discharge isolation valve, (4) WBS 2410 at the foundation, anchor bolt point for the foundations for the compressors, (5) and at the flange connections at the main cooling water distribution header where the cooling water is piped to the individual compressors.

### 3220 Heaters and Coolers

The heating system described here is the air heating system used to ensure the tunnel and plenum pressurization air is at the same temperature as the rest of the tunnel circuit when it is admitted into the tunnel. This is to prevent any thermal stratification or any other "cold spots" in the tunnel. The model propulsion air heating system is described in WBS element 3620. There are no coolers currently described in this section.

The local plenum air heater system is a 4 MW electric resistance type air heater. The purpose of this system is to ensure the plenum air is at the tunnel temperature so that once tunnel flow is re-established, there is not a bubble of cold air being pushed around the circuit. The system includes the air heater, the SCR controller, the local power panel and interconnecting wiring, and the air distribution system from the flange connection off of the main plenum supply line up to the flange connection back into the main plenum supply line (i. e., this is a bypass type of arrangement to the air heater with an upstream and downstream isolation valves for maintenance.

Significant interfaces: The plenum air heating system interfaces are (similar both LSWT and TSWT): (1) WBS 3290 and 32B0 - at two flanges in the 300 psig tunnel/plenum pressurization line where the line branches to the heating system or to the plenum entry and where the heated air is reintroduced, (2) WBS 4100 and 5100 - foundations for the mounting of the heaters to the Acoustic Enclosure foundation, (3) WBS XXXX - the LSWT or the TSWT power system (most likely at a 480 VAC power panel), (4) WBS 7200 for the instrumentation and controls, and

(5) WBS 3250 - discharge to the local vent system which is used for venting to atmosphere during preheat evolutions.

### 3230 Drier Systems

An automatic air drying system is provided to remove the moisture in the air stream and provide a  $-60^{\circ}\text{F}$  dew point at 300 psig. This system is located downstream of the 300 psig compressor system and upstream of the 5 micron filters and high pressure compressors. The drying system is five parallel dryers to provide a degree of redundancy as well as to keep the system size reasonable. Each dryer is dedicated to a specific low pressure air compressor.

Moisture separation is accomplished using set of vane separators/mist eliminators that are used to remove the bulk of the condensed liquid carried over from the aftercooler. In addition, a bank of five coalescing filters is provided in order to remove the last traces of entrained liquid water and any oil vapors.

The dryers are designed to remove water vapor from the air stream.. Each air drier package consists of two desiccant filled dryer towers and associated regeneration heater, blower, and valving and back pressure regulator which prevents inadvertent rapid blowdown of the dryers and damage or carryover of the desiccant. The dryers use an automatic regeneration circuit to minimize operator requirements. The regeneration circuit is accomplished using a natural gas fired burner with an air blower passing ambient air through the heat exchanger. The heated air is passed through the reactivating dryer tower and discharged to atmosphere. All controls, valving, support structure, etc. necessary for the dryer are considered as part of this element. The backpressure regulator while it is part of the overall dryer package, the physical location of the installation will be accomplished by others in the field.

The high pressure air dryer system is similar to the 300 psig dryer system. Two air dryers are provided downstream of the high pressure air compressors. The high pressure air dryers will provide a dew point of  $-60^{\circ}\text{F}$  at 4500 psig. Each air drier package consists of two desiccant filled dryer towers and associated regeneration heater, blower, and valving and back pressure regulator which prevents inadvertent rapid blowdown of the dryers and damage or carryover of the desiccant. The dryers use an automatic regeneration circuit to minimize operator requirements. The regeneration circuit is accomplished using a natural gas fired burner with an air blower passing ambient air through the heat exchanger. The heated air is passed through the reactivating dryer tower and discharged to atmosphere. All controls, valving, support structure, etc. necessary for the dryer are considered as part of this element. The backpressure regulator while it is part of the overall dryer package, the physical location of the installation will be accomplished by others in the field.

Significant interfaces: The air dryer interfaces are: (1) WBS 3250 - at the inlet and outlet flanges of the dryers, (2) WBS 3620 - at the discharge flange of the discharge isolation valve of each high pressure dryer package, (3) WBS 1350 - at the building 5 foot line where the natural gas enters the facility, (4) service air multiple uses, (5) WBS XXXX - power from a local 480 VAC power panel in the vicinity to be used for powering the blowers and the electrically operated motor valves, (6) WBS 7200 - instrumentation output, and (7) WBS 8000 - permits for the discharge of the combustion products.

### 3240      Filters

Air filters are provided in the 300 psig air distribution system to remove particulates of desiccant that may have been carried over from the dryers as well as any pipe scale or rust. The filters are rated for a 5 micron absolute filtration capacity. The filters are arranged in a bank of nine parallel filters in order to provide a degree of redundancy as well as to reduce the maintenance impact associated with changing large filter elements. The filters utilize a high collapse pressure rating for the elements (100% of the system design pressure) to ensure good quality elements and to prevent premature failure/collapse of the element. The filter elements are stainless steel mesh elements. The filter system includes the filter housings and elements, interconnecting piping to the other filters, isolation valves on either side of each filter, and connections for differential pressure measuring instrumentation.

A set of four filters are provided at the inlets to the high pressure compressors. These filters are identical to the filters downstream of the dryers. These filters remove any pipe scale or other material that may be in the line between the air dryers and the inlets to the compressors. These filters provide a 5 micron absolute filtration capability.

A set of high pressure filters is provided in the Model propulsion air system. These filters are located at each end user (LSWT, TSWT, and all test and cal. labs in the Model Prep. building). These filters are rated for 5000 psig with a 5 micron nominal filtration rating. These filters prevent any damage to the internals of any Turbine Powered Simulators or any other nozzle surfaces. It is extremely important that the high pressure filters provide the required filtration to minimize the potential damage to models. In addition, these filters will have a high collapse pressure rating, at least 3000 psid differential pressure. The filter elements will be stainless steel mesh elements. A total of ten filters are included.

Significant interfaces: The filter system interfaces are: (1) WBS 3250 - at the upstream and downstream flanges of the filter banks, (2) WBS 7200 - instrumentation monitoring, (3) WBS 2410 - foundations for the filter housings and valves, and (4) 3620 High pressure air system.

## 3250      Distribution

The distribution system is a complicated network of piping and valving to provide the compressed services and vacuum services to all of the users. Note that the cooling water and associated components and the 4500 psig model propulsion air distribution systems are provided in other WBS elements. Providing the services to the end users requires an integrated plan to minimize the lengths of pipes, and to minimize the number of valves in the system. A centralized valve position monitoring and control system will be incorporated in order to ascertain the system configuration at any time. The distribution system includes the piping, fittings, valves, gages, supports, and all installation and testing elements associated with the system. Note that the monitoring and control instrumentation is provided in WBS 7200. Tabulated below are the services provided, the approximate lengths of pipe, the design conditions, and the sizes of the lines.

Significant interfaces: The distribution system interfaces with most of the auxiliary process components. The significant components are: (1) WBS 3210 - compressors, typically at the compressor input/discharge flanges, (2) WBS 3230 - dryers, at the input/discharge flanges, (3) WBS 3220 - at the heater system inlet/discharge flanges, (4) WBS XXXX - power for electric motors on valves, and (5) WBS 7200 - control and instrumentation.

**Table 3250.1 Low Pressure Air Distribution System Table**

Service	Pressure (psia)	Length (ft)	O.D. (in)	Wall Thk (sch/in)
300 Psig compressor suction from the tunnel connections up to the compressor inlet, including the inlet filter (460 pps)	0 - 80	2500 -LSWT add'tl 1500 - TSWT	60	1/2
LSWT and TSWT tunnel and plenum vents to mufflers (max of 2500 pps)	0 - 80	200 per tunnel	60	1/2
Vacuum pump suction from the tunnel shell penetrations to the pump inlet (max of 4 pps, or 50,000 SCFM)	0 - 80	2500 -LSWT add'tl 1500 - TSWT	30	1/2
Vacuum pump outlet to vent muffler	25	100	10	Sch 40
300 Psi distribution system to the: dryer inlet, from the dryer to the filters, from the filters to the storage, and from storage to HP compressors (460 pps)	350	1500 (total)	24	3/8
300 psi distribution to the LSWT, TSWT, and Model Prep. Bldg. (max of 460 pps)	350	2500 - LSWT add'tl 1500 - TSWT add'tl 1000 - Model Prep	36	1/2

### 3260 Storage Tanks

The storage system is used for three different levels of storage, vacuum, 300 psig, and 4500 psig. Each storage field includes the interconnecting manifolding, and all support structure. All the necessary isolation valves and overpressure protection are provided in WBS element 3250 and 3620. All instrumentation is provided under WBS 7200.

The vacuum storage is used to help ensure a ready supply of vacuum to aid in rapid evacuation of the LSWT and TSWT plenums during sub-atmospheric testing, as well as for other vacuum requirements. The vacuum storage is two 40 foot diameter spherical pressure vessels. The vessels include the necessary support structure and appropriate manways and all penetrations for instrumentation, etc.

The 300 psig storage is used to store the 300 psi compressed air. It serves as a buffer during the tunnel pressurization. The primary purpose is to provide the

required stored volume of air with the required driving potential to allow for rapid recovery of the plenum for each tunnel. The 300 psig air storage system is eight 40 foot diameter spherical pressure vessels. The vessels include the necessary support structure, appropriate manways and all penetrations for instrumentation, etc. Each vessel has a storage capacity of approximately 33,500 ft<sup>3</sup>, for a total storage capacity of 268,000 ft<sup>3</sup>.

The 4500 psig storage is used to store the model propulsion air to meet the specified flow and duration requirements. The storage field is composed of 16 inch diameter cylindrical vessels of varying lengths (average length is 30 feet). The total storage capacity of the 4500 psig storage field is 7000 ft<sup>3</sup>. Provisions will be provided to allow for future expansion to at least 20,000 ft<sup>3</sup>.

Significant interfaces: The storage system interfaces are: (1) WBS 3250 - distribution system at the flange connection where the supply/discharge manifolds connect to the distribution system, (2) foundations under WBS XXXX, and (3) WBS 7200 - instrumentation and control.

### 3270 Muffler Towers

Mufflers are used to attenuate noise generated by the emission of high pressure compressed gases. Each tunnel shell and plenum vent is routed to a muffler. Each compressor system has the inter-stage unloading valves and pressure relief valves routed to a muffler. The model preparation building propulsion air test facility will also require a muffler. In addition, the vent for each storage field will be routed to a muffler. A total of nine distributed mufflers and support towers are provided on site to exhaust pressurized air directly from each wind tunnel near the test section/air lock. One muffler tower is associated with the air calibration lab exhaust and one over each of the 2 specially equipped cart rooms in the LSWT/TSWT test prep/control building. The muffler system includes the muffler, and the support structure, including ladders, grating etc.

Significant interfaces: The muffler tower interfaces are at the distribution piping connections to the muffler inlet flanges and from the attachment of the support structure to the foundations.

### 3280 Vacuum System

The vacuum system provides the capability of pressure trim during sub-atmospheric testing. In addition, the vacuum system provides a means of supplying a low flow vacuum capability wherever it may be required. The vacuum system consists of two trains of twin lobe Roots blowers, 50% capacity each, with a total rated capacity of 50,000 SCFM and 2,000 hp, and two storage vessels (see WBS 3260). Each Roots blower train will have two stages, with intercoolers and after coolers. The vacuum system also includes the motor starter, switchgear

(if required), all necessary instrumentation, lube oil system, and the cooling system from the vacuum pump and heat exchangers back to the cooling tower distribution header connection.

Significant interfaces: The vacuum system interfaces are: (1) WBS 3250 - distribution system at the vacuum pump suction isolation valve inlet and discharge isolation valve outlet, (2) WBS XXXX - power from the Wind Tunnel/Pressurization building substation to the switchgear, (3) WBS 7200 - instrumentation and control, (4) WBS 2410 - foundation for the vacuum pump, and (5) WBS 3440 - cooling water distribution piping.

### 3300 HEAVY GAS PROCESSING SYSTEM

DELETED.

### 3400 COOLING SYSTEM

The cooling system is a centralized evaporative cooling system which supports low temperature rise waste heat exchangers in each of the two wind tunnels and the auxiliary support systems. The cooling system consists of a cooling tower, cooling water distribution pumps, cooling water supply and return piping, and all associated controls and chemical addition systems. The cooling system includes the cooling system components, all starters for all cooling equipment motors, and a switchgear for the cooling system, as well as all controls and instrumentation required.

#### 3410 Cooling Towers

The cooling tower is fan-driven, upward forced-air evaporative type. The required duty is  $1,800 \times 10^6$  BTU/hr. The cooling tower is sized based on a total flow rate of approximately 300,000 gpm and a temperature change of approximately 10°F. The tower structure is treated timbers with a PVC type of fill. The tower fill and fans and all structures are set on separate sealed basin foundation. Height of towers is dependent on location relative to nearby buildings and other site features to minimize air flow blockage and effects of fog plume. The tower uses chemical treatment methods to control the growth of algae, etc. The tower will utilize makeup water to account for evaporative and windage losses. The makeup capacity requirements are approximately 3% of the total flow or 11,000 gpm.

Significant interfaces: The cooling tower interfaces are: (1) WBS 3420 Cooling water circulation pumps, (2) WBS 3440 cooling water distribution piping, (3) WBS 1400 power for the fans and pumps, (4) WBS 7200 controls and instrumentation, (5) WBS 1330 makeup water, and (6) WBS 1340 waste water treatment and discharge.

### 3420 Cooling Water Circulation Pumps

The cooling water circulation system has a required capacity of approximately 300,000 gpm. The pumping system is composed of the pumps and all associated suction and discharge valves, and instrumentation. The pump system is composed of five pumps each rated for 65,000 gpm (this provides one installed spare pump), 100' Total Dynamic Head for each pump, motor size of 2200 hp, and rotating at 500 RPM. The pumps are horizontal centrifugal pumps. This system also includes the pump motor starters and the associated switchgear.

Significant interfaces: The cooling water circulation water pump interfaces are: (1) WBS 3440 cooling water distribution piping, (2) WBS 1400 power for the pumps, (3) WBS 7200 instrumentation and controls, and (4) WBS 8000 permits for discharge of waste water.

### 3430 Miscellaneous Equipment

The miscellaneous equipment includes primarily the ancillary components required for the systems. Items such as the screens at cooling tower basin and the chemical addition system are included here.

Significant interfaces: The miscellaneous equipment interfaces are primarily associated with the other elements of the cooling system and are not discussed here.

### 3440 Distribution System

The distribution system includes all piping, mains, laterals, valves, fittings, gages, trenching etc. for routing the cooling water up to the associated facilities. The termination points of the distribution system are considered to be inside the facilities where headers are divided to feed the individual components. At those points, the system is considered to be part of the individual component. The distribution piping that is larger than 36 inch diameter will be reinforced concrete piping. All cooling water piping 36 inch and smaller will be carbon steel piping. Where possible, the cooling water piping will utilize utility tunnels. However, the 76 inch and 90 inch concrete piping will be direct buried and not routed through the utility tunnels, primarily because of the sizes of the lines and the impact on the utility tunnels. The distribution system is shown in the table below. Shown are the pressures, flows, lengths, and line sizes of the main cooling water supply/return systems.

Significant interfaces: The cooling water distribution system interfaces are similar to the compressed gas system interfaces in that they are connected to a number of different components. The notable components/systems are: (1) WBS 4440 LSWT heat exchanger, (2) WBS 5440 TSWT heat exchanger, (3) WBS 3210 all

of the auxiliary compressors, and (4) WBS 3410 and 3420 cooling tower and cooling pumps.

**Table 3440.1 Cooling Water Distribution System**

Service	Flow (gpm)	Length (ft)	O.D. (in)	Wall Thk (in)
Cooling water supply/return from tower to Main lateral (concrete pipe)	300,000	1500	90	8
Cooling water supply/return from main lateral to LSWT (steel pipe)	60,000	1500	36	1/2
Cooling water supply/return from main lateral to TSWT (concrete pipe)	160,000	1500	76	7
Cooling water supply/return from main to Wind Tunnel Press./Vacuum Building (steel pipe)	80,000	1500	36	1/2

### 3500 TSWT-DRIVE SYSTEM

This has been transferred to WBS 5700.

### 3600 MISCELLANEOUS SUPPORT SYSTEMS

#### 3610 Tunnel Cleaning System

A single, mobile tunnel cleaning system is provided. The system as currently envisioned provides removable work platforms and removable cables. The work platforms will traverse the cables and allow personnel to inspect, clean, and repair all flow conditioning elements, heat exchangers, and turning vanes.

#### 3620 Calibration System

The calibration system is the Model Propulsion air system, 4500 psig system. This system begins at the high pressure storage field and is routed to all end users. End users are the LSWT and TSWT as well as the Model Preparation Building and all necessary test cells. The system includes the capability of heating the air as well as collecting and venting to atmosphere, the air used in calibration testing.

The distribution system is composed of 10 inch special wall thickness piping (see table), numerous isolation and control valves, and the necessary heating systems. Three heating systems have been included. Two of the heating systems are located at each tunnel to provide the heat necessary for the TPS and UPS testing. A third heating system has been provided for the Open Jet Test Cart for the HSCT Nozzle testing.

The TPS and UPS heating system at the LSWT serves LSWT and the adjacent test cell (cart room) as well as the air calibration laboratory. The TPS and UPS heating system at the TSWT serves the TSWT and the adjacent test cell (cart room). Each heating system is used for the model propulsion air system heating. Each system is capable of providing sufficient energy to continuously heat 40 pounds per second of air from 60°F to 500°F. Each heating system is a gas fired indirect heat exchanger. The products of combustion are used to heat the model propulsion air as it passes through a series of stainless steel tubes. The products of combustion are ducted to the environment. Appropriate methods of meeting the air quality standards for the locality will be incorporated into each heating system. By using an indirect fired heat exchanger, the air system is not contaminated with the combustion products, as well as the system can be operated indefinitely. The system includes the heat exchanger, a pressure control valve, a bypass control valve for air temperature control, the gas burner, the exhaust system up to the discharge to atmosphere, and the gas supply system from the building 5 foot line up to the burner. Each heating system has a dedicated distribution system to the end users.

The HSCT heating system is a vitiated heating system that is mounted to the open jet test section cart. This system uses a burner fueled by natural gas and an attenuation device to reduce the noise of the combustion process. The burner is mounted onto the Open Jet Test Section cart. Therefore, air and natural gas are required to be connected to the cart with mechanical joints. This type of testing occurs infrequently. Therefore, only one burner and sound suppression system has been provided. This system is modular and can be built up in the Open Jet Test Section Cart Room and verified prior to mounting it to the cart. The lines will all be required to be either internally insulated or fabricated from a high temperature alloy steel such as Haynes 230 alloy.

**Table 3620.1 High Pressure Air Distribution System**

Service	Pressure (psia)	Length (ft)	O.D. (in)	Wall Thk (sch/in)
4500 psig distribution from compressor output to high pressure storage (140 pps)	5000	300	10	1.3
4500 psig distribution from storage to LSWT plenum, TSWT plenum, Model prep. bldg. and Air Heaters (max of 140 pps)	5000	2500	10	1.3
4500 psig distribution from storage to LSWT or TSWT Air Heaters to LSWT or TSWT plenums (max of 50 pps)	5000	200	10	1.5

Significant interfaces: The model propulsion air heating system interfaces are: (1) WBS 3250 - the flange at the high pressure air distribution line where it either enters the air heating area or continues on to the end users, (2) WBS 3250 - the flange at the heated air distribution outlet at the building 5 foot line to the dedicated heated air distribution system, (3) WBS 1350 - the building 5 foot line where the natural gas supply enters the building, (4) WBS 2460 - the foundation for the air heaters, (Other Minor Buildings), (5) WBS 7200 - controls and instrumentation, (externally supplied temperature setpoint), (6) WBS 8000 - permits for the discharge of the combustion products.

**3630 Compressor Blade Handling System**

The compressor blade handling system has been transferred to WBS elements 4700 and 5700.

**3700 SCAVENGING AND FIRE SUPERVISION SYSTEMS**

**3710 Combustion Gas Scavenging Systems**

DELETED.

**3720 Tunnel Fire Suppression System**

DELETED BECAUSE 3710 DELETED.

**3800 AUXILIARY ELECTRICAL, CONTROL SYSTEMS AND DATA ACQUISITION**

**3810 Electrical Equipment**

This WBS provides the 480 volt substation secondary switchgear and load centers; 480 volt motor control centers, power distribution panels; DC system equipment with batteries, chargers, distribution panels, and motor control; and the Uninterruptible Power System (UPS) with batteries, inverters, switching, and distribution panels. This WBS also includes the wiring and cable tray conduit systems for connection of the electrical equipment.

**3820 Electrical Materials**

Included with WBS 3810.

**3830 Control Systems**

This element has been transferred to WBS element 7000.

**3840 Data Acquisition and Processing Systems**

This element has been transferred to WBS element 7000.

**3900 AUXILIARY TEST AND VALIDATION**

**3910 Test and Validation**

The Auxiliary Process Systems sub-systems will be tested to demonstrate performance to specified levels. The work associated with shop tests is included with individual work packages. Once installed, subsystem checkouts and integrated system tests will be performed to verify performance parameters. Test and validation hardware is provided in WBS 7000.

**3920 Calibration**

Components and sub-systems will be calibrated. Calibration hardware is provided in WBS 7000.

**3A00 PRODUCTIVITY PROVISIONS**

Since production is critical to this facility, duplicate components are required in critical areas so downtime to the facility can be minimized. Any component which has a significant probability of failure, which is critical to the Auxiliary Process System operation, needs to be in stock at the facility or available from a supplier, ready for immediate delivery.

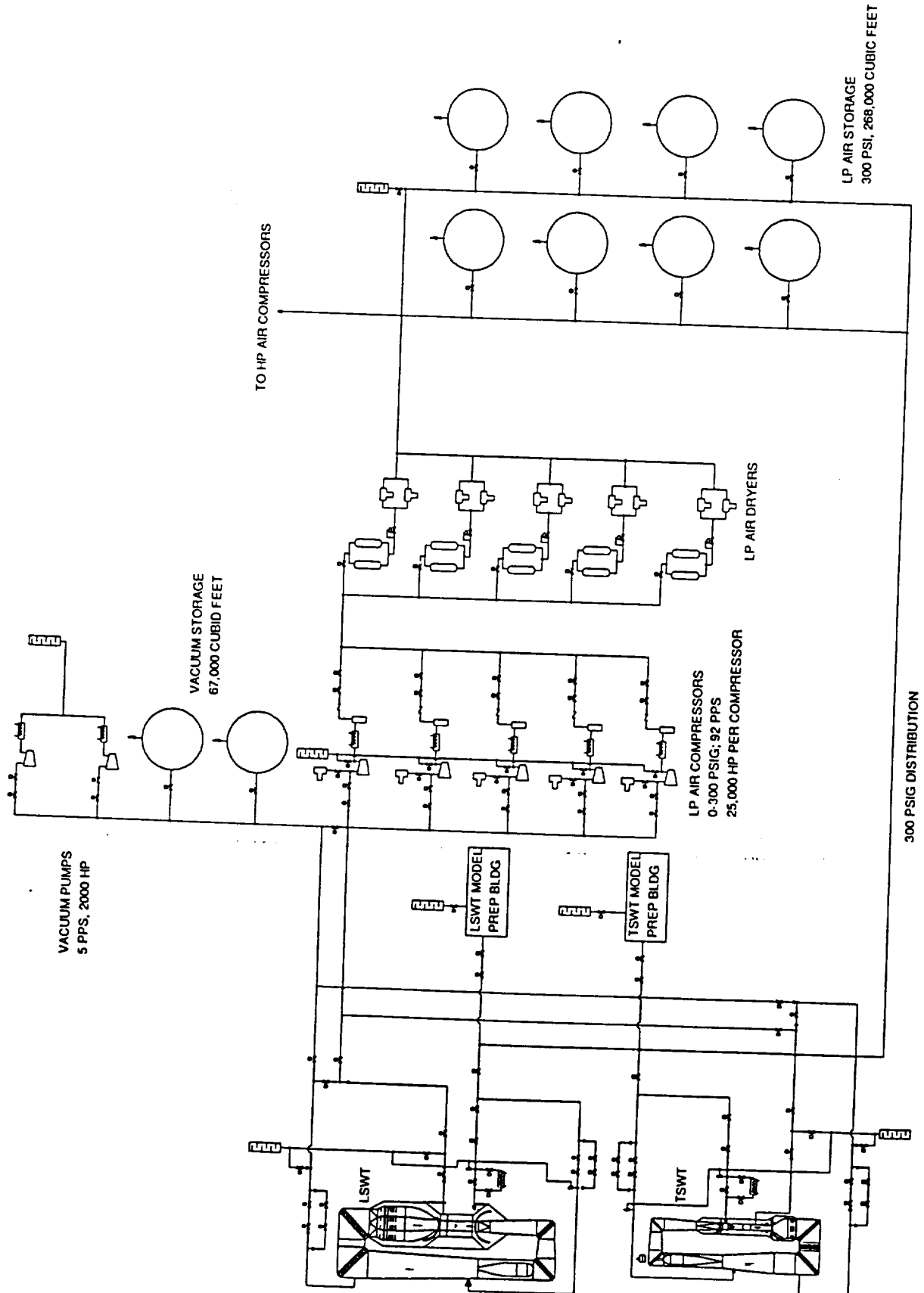


Figure 3200.a Low Pressure Air System Schematic

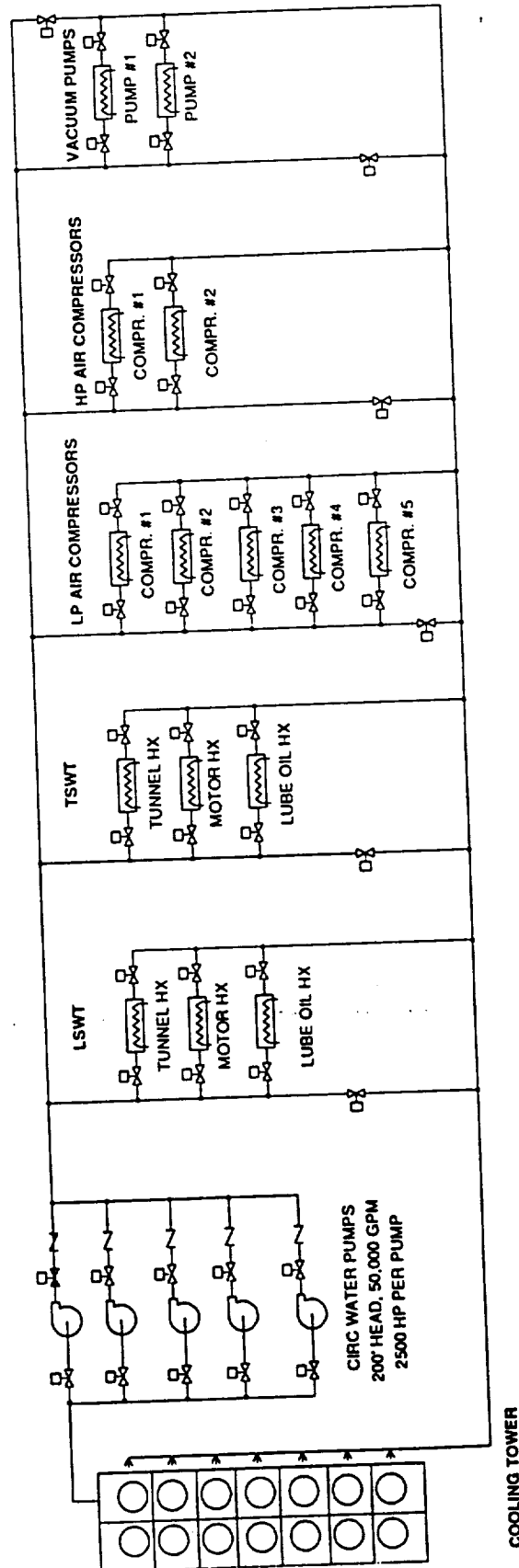


FIGURE 3400.a Cooling Water System Schematic

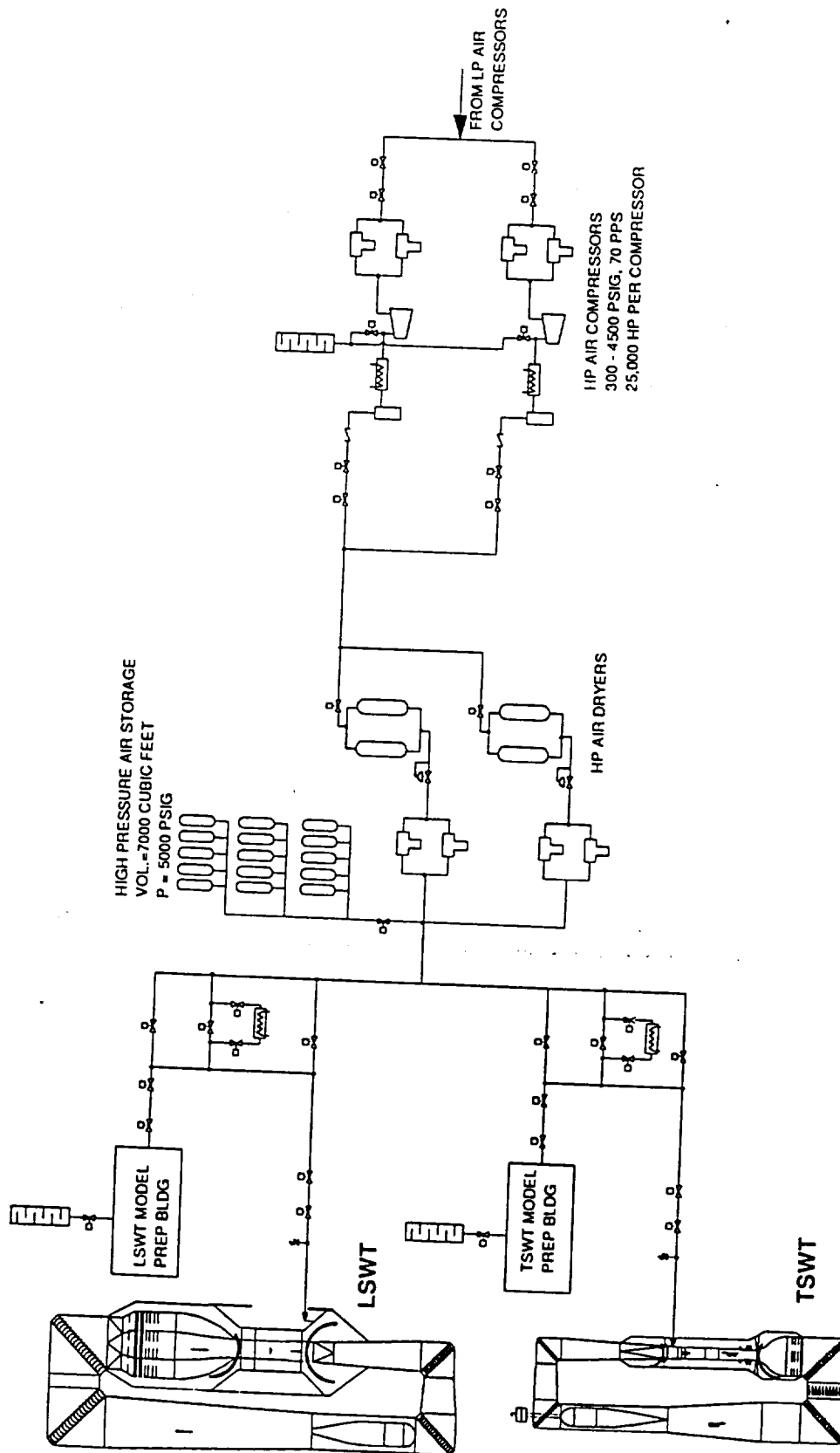


FIGURE 3600.a High Pressure Air System Schematic

## **4000 LOW SPEED WIND TUNNEL (LSWT)**

### **4100 LSWT ENCLOSURE**

#### **4110 LSWT Enclosure Foundation**

The LSWT enclosure and pressure shell, exclusive of the tunnel compressor section, are supported on a common foundation. The foundation consists of a reinforced concrete basemat with embedded plates and bolts to facilitate the attachment of acoustic enclosure steel and pressure shell supports and anchors. The basemat is eight feet thick, with plan dimensions of 625 ft x 270 ft. It is a stepped design, varying from grade level to 38 feet below grade. The compressor section is supported on a foundation common with the drive system, but isolated from the rest of the tunnel circuit.

#### **4120 LSWT Enclosure**

The building surrounding the tunnel pressure shell serves two main purposes: (1) To reduce sound emanating from the LSWT to acceptable levels on site and at the site boundary, and (2) To provide a more stable controlled environment for the tunnel shell since operating conditions and hence test results would be compromised. The building consists of a steel frame structure with metal siding and roofing measuring 625 ft x 270 ft x 110 ft high. It includes personnel doorways and large access doors as required for wind tunnel internal component removal. Four overhead bridge cranes, 300 ton capacity each, services the tunnel circuit, equipment and laydown space.

#### **4130 Acoustic Insulation**

Acoustic insulation lines the inner surfaces of the walls and roof and has been included in construction of the acoustic enclosure.

#### **4140 Electrical Services**

Basic building services including high bay lighting, and convenience and special purpose outlets that are located at multiple locations within the building. Data, communication, and fire alarm services are provided.

#### **4150 Mechanical Services**

Fire protection provided by mobile equipment. Hose cabinets included by main access doors. Service air outlets are located at multiple locations within the building. Heating and exhaust fans are provided.

#### **4200 LSWT PRESSURE SHELL**

This WBS item includes all components of the outer pressure containing shell of the LSWT, with the exception of the following:

- The LSWT Pressure Isolation System - included in WBS 4300.
- The LSWT Rolling Plenum - included in WBS 4500.
- The LSWT Compressor Section Shell - included in WBS 4700.

This item also includes the shell foundation, support structure, all tunnel shell penetrations, and external stiffening rings.

#### **4210 LSWT Support Foundation**

The LSWT pressure shell, exclusive of the tunnel compressor section, is supported on a common foundation. The foundation consists of a reinforced concrete basemat with embedded plates and bolts to facilitate the attachment of acoustic enclosure steel and pressure shell supports and anchors. The basemat is eight feet thick, with plan dimensions of 625 ft x 270 ft. It is a stepped design, varying from grade level to 38 feet below grade. The compressor section is supported on a foundation common with the drive system, but isolated from the rest of the tunnel circuit.

#### **4220 LSWT Support Structure**

The pressure vessel is supported above the foundation plates by column and cross braces with flex joints aligned to permit longitudinal and lateral movement with respect to the fixed anchor point at the compressor section. The supports are designed to support 203 million pounds of water weight for hydrostatic testing plus weight of pressure shell and internal equipment of 18 million pounds.- The tunnel center line is 29 ft above grade and 30 ft above the movable plenum rails.

- Material: SA516 Grade 70
- Weight: 4,120,000 LB

#### **4230 LSWT Pressure Shell**

The pressure shell is constructed of curved plates, ring girders, stringers, flanges, bulkheads, gussets, and stiffeners. The pressure shell is designed, constructed, inspected, tested, and U stamped in accordance with the ASME Code Section VIII. The pressure shell will interface with the test section plenum and compressor sections. Penetrations are provided for instrumentation, tunnel, pressurization/evacuation, drive shaft, manways, cooling water, and lubrication.

The tunnel cross section is circular with square corner and conical sections. It is the flow boundary except through the settling chamber/contraction/test section regions.

**Table 4230.1 LSWT Pressure Shell Description**

Parameter	Description
Operating pressure	0.07 to 5 atm
Design pressure	-15 to 65 psi gauge
Design temperature	ambient to ambient + 30° F
Mach No. range	0.05 to 0.60
Dimensions	
Flow centerline	1,115 ft
Plenum diameter	104 ft
Movable plenum	51 ft. dia. by 59 ft.
Compressor	44 ft. dia by 39 ft
Internal volume	3.25 million ft <sup>3</sup>
Shell Material	SA516 Grade 70
Coatings	Interior and exterior surfaces are painted
Weight	29.6 million LB empty

#### 4300 LSWT PRESSURE ISOLATION SYSTEM

The system includes two sliding gate valves on the wind tunnel pressure shell on each end of the 76 ft long test section for pressure isolation at a face-to-face spacing of 88 ft.

Note: The air lock access door is not required for this concept.

#### 4310 LSWT Isolation Valves

Two sliding gate valves, each consisting of a 2 inch thick semi-elliptical heads with full edge flanges are required. The valves may be designed horizontally or vertically. Each valve is powered by a hydraulic actuator through a double rack and pinion drive. The gate of the valve slides in a guided rail system. The valves are stored in a well beneath or to the side of the tunnel flow stream completely enclosed in the pressure plenum.

- Size: Elliptical shape 60 ft wide x 32 ft high by 10 ft deep carriage
- Weight: 70 tons each

- Material: Welded mild carbon steel, ASME SA 516, Grade 70
- Rating: 75 psia maximum working pressure on either side. 1 psia minimum working pressure on either side.
- Seals: Active trapped continuous pressure seals on mating surfaces of pressure shell bulkhead in open and closed positions, with Teflon seal material, pressurized dry nitrogen activated.

#### **4320 LSWT Access Door**

A personnel door is provided in the fixed part of the plenum.

#### **4330 LSWT Hydraulic Power Unit**

A hydraulic power unit is provided to actuate the two isolation doors. The size of the hydraulic power unit is: 25 hp, 3000 psi.

#### **4400 LSWT FLOW INTERNALS**

This WBS line item includes all components internal to the stationary pressure shell provided for the purpose of controlling the air flow qualities in the wind tunnel. This WBS item does not include the test section carts, which are in WBS 4500.

#### **4410 LSWT Turning Vanes**

This WBS item includes four turning vane assemblies, which direct the air flow around each of the 90 ° corners of the LSWT. Each turning vane assembly is an integral unit complete with splitter plates and access doors. The turning vanes are supported by the pressure shell by radial expansion type connectors.

##### **Turning Vanes #1 and #4**

The function of the turning vanes is to change the direction of air flow at the corners with minimal distortion and pressure loss. The turning vanes located in corners #1 and #4 are acoustically treated. The vanes in corners #1 and #4 are acoustically insulated on the leading edge to reduce the fan noise effects in the test section by approximately 15 dB. The desired turning vane spacing to cord distance ratio is 0.30.

For turning vane set #1:

- Dimensions: 19 turning vanes - cord length 7'-1"; approximately 9 feet wide by an average length of 28 feet; average wall thickness

0.5".

- Material: Carbon steel plate (machined leading and trailing edges to airfoil shape) with cross ties every 5 ft.
- Weight: 66 tons including supports.

For turning vane set #4:

- Dimensions: 20 turning vanes - cord length 9'-11"; approximately 11 feet wide by an average length of 45 feet; average wall thickness 0.5".
- Material: Carbon steel plate (machined leading and trailing edges to airfoil shape) with cross ties every 5 ft.
- Weight: 150 tons including supports.

Turning Vanes #2 and #3

Non-acoustic turning vanes are located in corners #2 and #3. The desired turning vane spacing to cord distance ratio is 0.30.

For turning vane set #2:

- Dimensions: 20 turning vanes - cord length 7'-11"; approximately 8 feet wide by an average length of 30 feet; Average wall thickness 0.5".
- Material: Carbon steel plate (machined leading and trailing edges to airfoil shape) with cross ties every 5 ft.
- Weight: 75 tons including supports.

For turning vane set #3 (Same as #4):

- Dimensions: 34 turning vanes - cord length 9'-11"; approximately 11 feet wide by an average length of 45 feet; average wall thickness 0.5".
- Material: Carbon steel plate (machined leading and trailing edges to airfoil shape) with cross ties every 5 ft.
- Weight: 150 tons including supports.

**4420 LSWT Honeycomb**

One set of straightening vanes is required to obtain quality flow in the test section. The straightening vanes are located upstream of the screens in the settling chamber and consist of hexagonal honeycomb panels assembled and held in a structural frame. The honeycomb reduces the turbulence levels by a factor of 2 and angularity by a factor of 10.

- Configuration: 1/2" Cell x 5" Thick, l/d = 10:1
- Material: Stainless Steel

**4430 LSWT Screens**

The screens reduce turbulence levels and flow angularity such that in combination with the other flow conditioning items, the turbulence levels in the test section are less than .08% and flow angularity is less than 0.03 degrees. The LSWT uses four anti-turbulence screens. The four anti-turbulence screen sets are located in the settling chamber section downstream of the honeycomb. The settling chamber screens require pre tensioning and are mounted to an outer frame. Because of the hexagonal shape of the diffuser and settling chamber cross sections, additional consideration must be given to the method of attachment and tensioning system to minimize screen attachment stresses. One additional screen set is located in the wide angle diffuser section.

- Dimensions: 5200 square feet per screen section.
- Screen Size: The following screen sizes are assumed:
  - Diffuser (1): 0.024" dia x 11 mesh (53% open area)
  - Settling Chamber (4): 0.023" dia: x 10 mesh (59% open area)

Note: Open area for the screen in the settling chamber should be larger than 57% and wire diameters should be no greater than 0.098".

- Materials: Stainless Steel

**4440 LSWT Internal Heat Exchanger**

The tunnel air is cooled by an air to water heat exchanger located in the entrance to the settling chamber. The internal heat exchanger is part of the tunnel cooling system consisting of cooling towers, pumps and interconnecting piping. Process system components other than the internal heat exchanger are located in WBS 1330. Tunnel penetrations are located in WBS 4230. The function of the heat exchanger is to remove heat of compression introduced by the fan and limit the

operating temperature to a maximum of ambient plus 30 degrees F.

The heat exchanger consists of multiple passes of vertical copper finned tubes. The tunnel cross section is made up of approximately 88 - 4 foot X 11 foot modules, which are brazed together in place. The modules are modified to accommodate the hexagonal settling chamber cross section. The vertical tubes are supported from the top and are also supported by airfoil shaped horizontal supports. Supply and return water alternates from tube to tube across the entire diameter to eliminate flow stratification and provide an evenly distributed temperature profile. The supply and return mains are located in recessed pockets in the top and bottom of the settling chamber. A tradeoff study is required to evaluate the need for elliptical shaped tubes to minimize flow disturbances as the air passes through the heat exchanger. The design incorporates:

- Dimensions: 82 ft long. x 3 ft thick mounted inside a 90 ft ID settling chamber portion of the pressure shell. Exchanger modules (4 ft x 11 ft cross sections) connected to piping supply and return mains, aligned in vertical struts with horizontal stiffeners.
- Capacity: Sized for 90,000 hp cooling. Holds ambient temperature in test section( i.e., + 30° F).

#### **4450 LSWT Settling Chamber Liner**

The settling chamber liner consists of the wide angle diffuser, settling chamber, contraction nozzle, and subsonic nozzle. It provides mounts for the heat exchanger, honeycomb and screens. It also provides structural framing for mounting the liner to the pressure vessel shell attachment points.

- Wide Angle Diffuser: The wide angle diffuser is a six-sided expansion section that supports one screen section and interfaces with the pressure shell and the settling chamber. Dimensions: 74'-8" high x 74'-8" wide with 21'-10" corners expanding to 95'-8" high x 95'-8" wide with 28'-0" corners x 16 ft long.
- Settling Chamber: The settling chamber is a six-sided section with constant cross section that supports the heat exchanger, honeycomb and four screens. Dimensions: 95'-8" high x 95'-8" wide with 28'-0" corners x 56'-7" long.
- Contraction Nozzle: The contraction nozzle is a six-sided section that compresses the flow and extends from the settling chamber to the upstream isolation valve. Dimensions: 95'-8" high x 95'-8" wide with 28'-0" corners at the large end, 20' high x 24' wide with 5'-0" corners at the small end, and 68'-4" long.

- Subsonic Nozzle: The subsonic nozzle is a four-sided weldment, fabricated from steel plate, with fillets in each corner, and reinforced with structural stiffeners. The nozzle extends from the upstream isolation valve to the entrance to the test section. It does not move with the test section components. Dimensions: 24 ft wide x 20 ft high x 17 ft long.

**4460 LSWT Plenum Evacuation System (Deleted)**

The plenum evacuation system use not being used in this concept.

**4470 LSWT Heavy Gas Manifolding (Deleted)**

The heavy gas system is not being used in this concept.

**4480 LSWT High Speed Diffuser**

The high speed diffuser is a structural steel weldment which starts at the downstream end of the isolation valve and ends at the conical diffuser section. It provides a transition from rectangular to round cross section.

- Dimensions: 20 ft high x 24 ft wide, to circular cross section, 31'-8" diameter over 26'-10" of length and continues to expand to 31'-10" diameter over the next 44 ft. The total length of the high speed diffuser is 65 ft.
- Weight: 115 tons

**4490 Acoustic Treatment For Nacelle and Walls**

Acoustic treatment is being used in this concept. Acoustic treatment is located on the fan nacelle and tunnel pressure shell in the vicinity of the compressor.

**44A0 Compressor FOD Protection**

A screen section is required on or just upstream of the turning vane set # 2 to protect the fan blades from debris. This screen section is a coarse mesh screen which may or may not extend the full height of the cross section.

**44B0 Acoustic Baffles (Deleted)**

Acoustic baffles are not being used in this concept.

**44C0 Tunnel Cleaning System**

Transferred To WBS 3610

**4500 LSWT TEST PLENUM**

**4510 Subsonic Nozzle**

The subsonic nozzle is located in WBS item 4450.

**4520 Flutter Test Section(Deleted)**

Flutter testing capability has been deleted.

**4530 Open Jet Test Section**

An open jet test configuration is required for Concept A (Mod) for operation up to 1 atmosphere tunnel stagnation pressure and at ambient temperature. The method used for accomplishing this testing is to build up an open jet test configuration on a movable cart which replaces the movable plenum section in Concept A. The open jet testing for Concept C has an open jet length of 45 ft and an acoustic measurement radius of 45 ft. Components required for the various required test configurations are: Open Jet Collector, Open Jet Nozzle Lip Extension, Open Jet Rear Sting Mount, Open Jet Floor Mount, Open Jet Floor Mount Traversing System (used in Concept C only), Open Jet Microphone Wing Traversing System, Open Jet Transport Cart, and an Anechoic Room.

- **Open Jet Collector:** The collector assembly consists of the collector and support structure to mount the collector to the transport cart. The collector and support structure have to withstand aerodynamic loads up to  $M=0.6$ , 1 atm., and ambient temperature operation. The Open Jet Collector is bolted to the transfer cart, but provisions should be made for manually adjusting the axial position of the collector in the test section. Both the collector and the support structure require acoustic treatment. The collector is required for all open jet testing. Dimensions : 28 ft wide x 23 ft high (inlet)  
25 ft wide x 20 ft high (exit)  
9 ft long.
- **Open Jet Nozzle Lip Extension:** The nozzle lip extension mounts to the subsonic nozzle section and forms the lip of the nozzle for open jet testing. It is not acoustically treated. The nozzle lip extension is required for all open jet testing. Dimensions are: 24 ft wide x 20 ft high with fillets x 4 ft long.

- **Open Jet Rear Sting Mount:** The rear sting mount system is one of two ways to mount models in the open jet test section for acoustic testing. Model loads are transferred through the rear sting mount system to the open jet transport cart and then to ground through the outer pressure shell. The rear sting mounted system is designed to withstand loads of approximately 1/5 of the main vertical strut system (1 atm. testing only). Compatible stings shall be used where practical. The rear sting mount system is acoustically treated from the sting base to the cart floor. The rear sting mount system is bolted to the transfer cart, but provisions should be made for manually adjusting the axial position of the rear sting mount system in the test section. Model motions of pitch and roll are provided, along with some limited strut vertical travel. Model centerline position is maintained only over a portion of the pitch motion.
- **Open Jet Floor Mount:** A second model mounting configuration to be used primarily for propulsion testing is the floor or post mounted system. For Concept C, this system is mounted to the floor mount traversing system with a bolted interface. The traversing system positions the model at various locations in the test section. The Floor Mounted System incorporates a positioning turntable, which yaw motion while maintaining model position on centerline. The floor mount system is acoustically treated.
- **Open Jet Microphone Wing Traversing System:** A system for traversing a microphone rake in two dimensions is provided. This is included in WBS 7510, the LSWT Test Instrumentation.
- **Open Jet Transport Cart:** The open jet transport cart is provided to move the various open jet components between the test section and the model preparation area, and support the components in the test section, while being tested. The transport cart is a self propelled flat bed cart that operates on the same rail system used by the movable plenum. All elements of the open jet test section are built on platforms that mount on and are bolted to the transport cart. Movement of the transport cart into the test section completes most of the set up required for an acoustic test. The elevation of the model support cart floor is required to be as low as possible in the plenum. Included are wheels and motorized trucks, and an electrically actuated alignment and locking mechanism. The transport cart requires acoustic treatment covering the entire top of the cart. Since multiple configurations of the cart are possible, 30% extra acoustic wedge material is required. Dimensions: 59 ft long x 28 ft wide x 8 ft high

- Anechoic Room: An anechoic room is required for acoustic open jet testing. The anechoic room is discussed in WBS 4590.

#### **4540 Movable Plenum**

This WBS line item consists of the section of the LSWT pressure shell located between the two isolation valves. This section of the tunnel can be disconnected from the stationary pressure shell and rolled out of the circuit.

The movable plenum consists of the pressure shell, internal structural steel and rails to support the test section components, external structural steel to support wheels and motorized trucks, and inflatable seals

- Shell Material : SA516 Grade 70
- Weight : Plenum Shell - 900 tons  
Internal/External Structure - 200 tons  
Test Hardware - 300 - 400 tons  
Transport Cart - 150 tons  
Total - 1500 - 1800 tons

#### **4560 Observation System**

In-wall viewing ports and mounts are required for observing the model. Forty-five 6" diameter windows of optical quality and four 6" diameter windows of schlieren quality are provided. Window frames, window blanks, and mounting attachments for observation equipment (10) are supplied. Interchangeable window inserts are provided so that the window locations can be varied. The window glass, cameras, high intensity lights, lasers, etc. to record model test data and model response to control inputs are located in WBS 7000.

#### **4570 Test Section Carts**

The Test Section Cart work package includes all the movable sections necessary to build up the plenum into workable floor mounted and rear sting mounted model configurations. The carts have four test section walls and have an integrated model support system. The following carts are required:

- Rear Sting Cart: The rear sting cart is a four sided steel fabricated and machined structure with adjustable sidewalls which houses the Model Support Assembly. Included are wheels and motorized trucks for transporting the rear sting model cart into the test plenum. Also included is an electrically actuated alignment and locking mechanism. Dimensions of Rear Strut Model Cart: 30 ft wide x 24 ft

high x 59 ft long. Weight: 350 tons. The rear sting cart includes the following components:

- **Test Section:** The subsonic test section is a four sided steel structure with adjustable sidewalls and integral solid floor section. driven screw jacks. The subsonic test section and solid test section floor are fabricated and machined from structural steel.
- **Model Support Assembly:** The model support assembly consists of a vertical strut with a streamlined cross section, axial and lateral adjustable guide rollers, and a vertical drive assembly. The vertical drive assembly keeps the model on centerline during pitch motions.
- The pitch assembly is an integral part of the strut assembly. The pitch motion is achieved using differential motion of two vertical guide rods. The position is controlled by electric servo motors, driven through two rack and pinion drives. A roll coupling attaches to the strut by bolted interface. The roll mechanism consists of a high ratio gear unit with multiple drives. It must be designed for high model loads with minimal cross section for optimum blockage effects. Yaw positioning is not required for this concept. The stings for the rear sting cart are located in WBS 7430.
- **Floor Mount Cart:** The floor mount cart is a four sided steel fabricated and machined structure with adjustable sidewalls which houses the external balance model support assembly. Included are wheels and motorized trucks for transporting the floor mount model cart into the test plenum. Also included is an electrically actuated alignment and locking mechanism. Two floor mount carts are required for this concept for productivity reasons. Dimensions of Floor Mount Cart: 30 ft wide x 24 ft high (raised) or 27 ft high (lowered) x 59 ft long. Weight: 400 tons The Floor Mount Cart includes the following:
  - **Test Section:** The subsonic test section is a four sided steel structure with adjustable sidewalls and integral turntable floor section. The adjustable sidewalls are actuated by a series of electrically driven screw jacks. The subsonic test section and turntable test section floor are fabricated and machined from structural steel.
  - **External Balance Model Support Assembly:** The external balance

model support system contains an external balance support and translation system, including electro-mechanical actuators to vertically translate the external balance approximately 7 ft. The external balance, included in WBS 4680, is raised when the floor mount cart is moved and lowered when the external balance is in the installed position. It interfaces with a solid steel foundation permanently mounted in the movable plenum. Yaw positioning is obtained using the turntable actuation system. Roll positioning is not required for this concept. The floor mount struts are included in WBS 7430.

- Acoustic Open Jet Cart: Included in WBS 4530.
- Movable Ground Belt Cart: Not required in this concept.

#### **4580 Preparation Hall Shuttle Cart**

The Preparation Hall Shuttle Cart moves various test section and model support carts from bay to bay in the model preparation area. This cart lifts up to 100 tons and have the capability of accurately translating and positioning a load vertically up to 8 ft. The preparation hall shuttle cart is self powered and has the capability to operate independently of the rail system.

#### **4590 Anechoic Chamber**

An Anechoic Chamber is required in this concept for open jet acoustic testing. The anechoic chamber is permanently installed in the 104 ft diameter outer shell and consists of the following components: support structure, acoustic treatment, acoustic door.

- **Support Structure:** The support structure mounts the acoustic wedge panels and to put rectangular flats on the acoustic chamber walls. The support structure consists of longitudinal and lateral structural steel members welded to the outer shell. The steel backing structure for the acoustic panels is positioned to obtain a 45 ft clear radius for microphone measurements from the centerline to all treated walls (three foot wedge treatment).
- **Acoustic Treatment:** The acoustic walls are constructed of modular panels of sound absorbing material. The requirement is to achieve a cutoff frequency of 100 Hz in air. This requires a random incidence absorption coefficient of at least 0.99 at frequencies of 100 Hz and above. This is accomplished using glass fiber or foam wedges approximately 3 ft thick. The entire inner surface of the shell is covered with wedge panels.

- **Acoustic Door:** A roll-away door is required on the 104 ft dia shell to cover the test section opening. The door is constructed from 3/8" thick reinforced steel, rolled and welded in place. It is approximately 60 ft in diameter and curved to the shell contour. It is split in the middle and rolls on the tunnel shell in two directions. It contains acoustic treatment on the inner surface and is designed to withstand the test section static pressure load. A motorized drive system is included for automatic operation.

**4600 LSWT TEST SUPPORT EQUIPMENT**

**4610 Transferred to 4570**

**4620 Transferred to 7430**

**4630 Transferred to 7430**

**4650 Elevated Ground Plane**

The elevated ground plane is a lightweight aluminum honeycomb ground board with wedge-shaped removable piece at trailing edge to accommodate high angle of attack testing. Support system consists of four electrically driven jackscrews. Includes turntable to accommodate the single and three strut model supports.

**4660 Inverted Ground Plane**

The inverted ground plane is similar to the elevated ground plane. It is a lightweight aluminum honeycomb ground board attached to the test section ceiling with four manually driven jackscrews.

**4670 Transferred to 7430**

**4680 LSWT External Balance**

The external balance is a pyramidal balance mounted on a turntable, supplied with model support frame and test section floor turntable. The turntable and floor sections are in WBS 4570. The external balance is transportable between the model build up area and the movable test plenum. Efforts must be made during the design process to insure adequate stiffness in the balance support structure. A lifting mechanism is provided for balance removal. Calibration of the external balance is covered in WBS 7000.

## **4700 LSWT COMPRESSOR / DRIVE SYSTEM**

The Low Speed Wind Tunnel (LSWT) Drive System provides the shaft power and the compressor which produces LSWT air flow. The primary components are the motors, motor control system, compressor (fan) and related components which interconnect these elements into the LSWT drive train. The motor feed current is provided by the yard Electrical Power System (WBS 1400). The motors, shafts/bearings/seals which interconnect the motors into a drive train for the main compressor, and the lubrication/cooling systems for the drive motors are the major components. The performance requirements, physical arrangement and characteristics of the drive system are a product of the design and will flow from the aerodynamic performance, productivity and test unit reliability specified for the LSWT complex. Common design features and interchangeable equipment shall be used to the maximum extent practical throughout the LSWT/TSWT complex. Realistic utility ramp rate control issues shall be assumed for the chosen site and Electrical Yard Design when developing the peak instantaneous drive system accelerations/deceleration in response to LSWT performance demands.

The major compressor components are the rotating and stationary compressor hardware, including the compressor case which will complete the Pressure Shell and provides the structural load path to connect the compressor to its foundation, WBS 4210. The performance requirements flow down from the LSWT aerodynamic, flow quality, acoustic and productivity requirements. The design Mach/total pressure point coupled with maximum Mach Number required will determine the pressure ratio and drive system power requirements in conjunction with the maximum required model drag and the tunnel circuit resistance. The acoustic requirements are expected to be a major factor in the compressor (fan) design.

The detailed description, interface definitions and basis for cost estimates are given at the third tier level.

## **4710 Rotor Hub/Blades**

Provides the LSWT primary axial flow compressor shaft, structural mounting discs for the rotating blades and the rotating blades. The anticipated concept has fixed pitch rotor blades with the machine's variable geometry provided by the stators/IGVs/EGVs of WBS 4780. The stators are controllable with active control inputs from WBS 7730, Controls - LSWT. The IGVs and EGVs are adjustable but are expected to be kept in a fixed configuration for most operations once the facility checkout and calibration is complete. The blade and hub design shall readily allow repair and blade replacement to support high productivity. Provides 120 % spare blades, 110% of the spares are to be manufactured after performance acceptance of the compressor installed in the LSWT.

The rotor shaft interfaces with the two journal type bearings and the thrust bearing at the surface of rotation with the rotating surfaces the boundary of this work package and the adjacent stationary surfaces included in the bearings of WBS 4720. The drive shaft and related coupling fittings of WBS 4720 will interface at the first non-removable parting surface between the compressor shaft and the motor drive train. This work package will provide five (5) instrumented blades for each row which have been calibrated to provide maximum bending and torsional stresses. The instrumentation provisions to provide four channels of strain gage data channels per row plus four additional channels of rotor data to the tunnel shell are also included in this work package and these data channels will be interfaced with WBS 7570 (Process data instrumentation) external to the compressor shell. Only limited physical interface with the nacelles and supports of WBS 4730 and the stators/IGVs/EGVs WBS 4780 are expected but seals, critical tolerances and integral design requirements for compressor performance will require extensive interface during the design and installation of the compressor. The Lubrication and Cooling (WBS 4750) requirements will be provided by 4750 with the interface point at the bearing penetrations for lift/lube oil connections.

#### **4720      Shafts/Bearings/Clutches**

Provides the drive train components which interconnect the motors (WBS 4760) and mechanically connects the motor output to the tunnel circuit fan (compressor) for the LSWT. The major components of the package are the drive train shaft segments, couplings, bearings, clutches and directly related equipment. The drive train elements are required to transmit the full overload rating of the drive system on a routine basis, but will likely be sized based on maximum torque load for emergency stops and/or maximum acceleration. The couplings / clutches and mating interface surfaces are to be of common design for all motor interfaces. In addition to the hardware required to complete the drive train, a spare rotor which is physically and functionally interchangeable with any of the LSWT/TSWT main drive motor rotors is included. The drive train / coupling design is required to allow for the thermal expansion, relative movement and vibrations between the drive motors and LSWT compressor.

Five journal bearings and a single thrust bearing are anticipated, but the compressor design may result in a different configuration. All bearings shall be designed with slinger rings or a similar device to allow safe shutdown in the event of a lube system failure. The bearings are required to operate at the full range of LSWT conditions without loss of oil into the tunnel. Provides 50% replacement bearing inserts.

A turning gear system is provided on the compressor side of the motor coupling closest to the compressor. The turning gear, two speed: 1 rpm for shaft run out and 1/6 rpm for maintenance, requires sufficient torque and braking for safe

operations with the maximum rotor blade imbalance configuration.

The bearings will provide the stationary surface adjacent to the rotating surfaces of the rotor WBS 4710. The lubrication and cooling for the bearings will be provided by WBS 4750 and will interface at the first physical connection point external to the bearing case. The bearing design shall integrate the instrumentation provided by WBS 7570.

The coupling / clutch interface is required to mate with the appropriate motor rotor (WBS 4760) interface surface. All needed bolts and fittings required to complete the connection with the motors and associated couplings, clutches and compressor hub shaft ( WBS 4710) are included in this work package. The bearing foundations external to the tunnel shell are included in the LSWT Drive Building, WBS 2210. Lift / lube oil and related coolers interface at the penetration to the respective bearing case, with the piping and related hardware provided by WBS 4750, LSWT Lubrication and Cooling Systems. Health monitoring and diagnostic instrumentation will be provided by the Process Instrumentation work package 7570. Provisions for the integration of the WBS 7570 instrumentation will be made during the detailed design of each appropriate component of WBS 4720. The major shaft component(s) will almost certainly be the link between the bearing closest to the tunnel pressure shell and the compressor rotor hub. The seal around the shaft at the pressure shell penetration point will be included in this work package and will interface with the tunnel shell at a mating flange surface provide (WBS 4230) for this purpose.

#### **4730 LSWT Nacelles/Fairings and Supports**

Provides the aerodynamically contoured shell (teardrop shape) around the compressor hub and an symmetric airfoil fairing around the drive shaft of WBS 4720. The drive shaft fairing attaches to the pressure shell at the drive shaft penetration and extends through the turning vanes to the nacelle fairing. The primary supports of the compressor both forward and aft of the rotor blades constitute the principle load path for the compressor loads. The aerodynamic and structural requirements for these components are major factors in the compressor design effort. The required seals and directly related hardware to make the nacelle an effective aerodynamic shape are included in this package. Requirements for low turbulence and acoustic testing demand greater than normal care in the aerodynamics contouring of these fairings. The design and fabrication approach are likely to be affected. Maintenance and accessibility require special considerations if required productivity is to be attained.

The rotating portions of the nacelle attach to the rotor shaft and the interface is at the removable joint closest to the center of rotation with all fasteners provided with the fairings under this work package. The non-rotating portion of the nacelle will attach to the supports and provide the center body attachment for the

stators/IGVs/EGVs of WBS 4780. The interface with movable or adjustable components will be at the removable joint which separates the movable surface from the stationary elements. All stationary surfaces and mounting provisions are included in this package and all movable hardware and related fittings and fasteners are provided by WBS 4780.

The supports which provide the primary structural load path for the compressor loads interface with the pressure shell, WBS 4230 at the contour intersection between the two components unless the structural and fabrication approach indicate a more logical interface. The rotor end of the supports interfaces at the mating surface for the rotor bearings. The attachment provisions for the bearings are included herein and all fasteners and fittings are provided by WBS 4720.

The shaft fairing will interface with the pressure shell, WBS 4230 and turning vanes, WBS 5410 at the contour intersection between the two components unless the structural and fabrication approach indicate a more logical interface.

#### **4740 Gearboxes**

The current concept does not require any LSWT Main Drive Train gearboxes.

#### **4750 Lubrication and Cooling Systems**

Provides the lift/lubrication and cooling systems for the rotor bearings and main drive motor bearings of the LSWT. Water to oil heat exchangers for bearing lift/lube systems are included, as well as the related components needed for control and safety provisions. The design to properly size and locate the required equipment shall consider the LCC of maintenance and operations as well as the trade studies for construction cost. To the maximum extent practical, the components and subsystems used throughout the LSWT/TSWT complex shall be of common design and interchangeable. To facilitate maintenance and handling functions, the equipment included in this work package will be located below the main drive motor floor level. Cost / design trades are to determine the merits of large central systems verses smaller distributed subsystems through out the complex both LCC and reliability requirements must be included. High value equipment protection and reliability of total system performance are the major design requirements.

The bearing lift and lubrication systems and related heat exchangers, controls and pumps interface with the bearings at the physical connection closest to the bearing case/housing. All piping and fittings are included in this package. Electrical power and cooling water will be provided to all equipment in this work package by appropriate distribution systems in WBS 2210. The installation wiring and plumbing are included in this work package for the connection of these systems to normal distribution points for electrical and cooling water utilities in the

LSWT Drive Building, WBS 2210. Design requirements for equipment size, access and utilities will be input to the requirements of WBS 2210. Design loads for the cooling and lubrication requirements will be input from WBSs 4760 and 4720 and cooling loads will be input to WBS 3400, Cooling System. The required equipment includes 25% spares for pumps, valves and controls which are common to all similar systems.

Unless impractical, the journal bearings of WBSs 4760, 4720, 4720 and 4760 are all required to be physically and functionally interchangeable.

#### **4760 Motors**

The motor sizing and design are defined by the LSWT performance requirements and projected compressor design performance. The design continuous duty rating shall be 1.05 of the projected required shaft horsepower rating needed for the LSWT design point performance. An intermittent duty cycle is required at 1.20 the continuous duty cycle level for up to one hour with a one hour synchronous speed cool down at or below the continuous duty cycle maximum power level. The LSWT motor(s) shall be of common design, physically and functionally interchangeable to the extent practical with other large motors in the LSWT/TSWT complex. Major components should be interchangeable to the extent practical based on Life Cycle Cost considerations. The motor, drive shaft, building and support equipment shall provide the ability to remove the main drive motor from the LSWT Main Drive Train and install a replacement motor to reestablish drive capability within 24 hours.

The motor interface with the Motor Controls (WBS 4770) at the closest physical connection point to the motors. The electric requirement specifications are quoted for that interface point. The drive motor foundations are included in WBS 2210, LSWT Drive Building. Cooling air provisions for the motors are required in the design of these foundations. The motor bearing lubrication and related cooling are provided by WBS 4750 with the interface point at the motor housing penetration/flange. The rotor will interface to the drive train components (WBS 4720 Shafts/Bearings/Clutches at the parting surface of a coupling flange at both ends of the rotor shaft. A common flange configuration is required for all drive motor couplings. The coupling hardware (bolts, pins, etc.) are included in the WBS 4720 definition. WBS 4720 includes a journal type bearing to support each end of the rotor shaft. The interface surface is defined as the surface of rotation, i.e. the rotating shaft is part of the motor and the stationary bearing surface is included in the bearing package.

#### **4770 Motor Controls**

Provides the variable frequency start system and sub synchronous speed control system for the LSWT Main Drive Motors, WBS 4760. The major components of

the system includes the switch gear, harmonic filters and redundant power conditioning and directly related equipment. A major portion of the equipment will be located outdoors in the Station No. 1 area adjacent to the 138/13.8 kV conversion equipment of WBS 1400. All equipment must be provided with its own weather protection and sufficient environmental conditioning provisions to ensure reliable operations and most economical LCC. The primary design requirement is to accelerate to any desired speed above 5% of synchronous speed and maintain that speed  $\pm 1$  rpm indefinitely. The total drive train is required to accelerate to any demand speed in two minutes or less and stabilize at the demand speed within 10 seconds.

The Motor Controls system receives input power from the power conversion equipment in the Yard Electrical Power System, WBS 1400. The 13.8 kV input interfaces at the first physical connection point inside the initial enclosure(s) for the equipment in this work package. The output interface is the physical connection to the motors nearest the motor case/housing. All interconnections within and between elements of the Motor Controls equipment are included as part of this work package. The demand/set point control input to this equipment comes from WBS 7700 and the signal will be to the appropriate location for input to this equipment. Concrete pads for the installation of the Motor Controls system equipment are included in the WBS 1400 (Yard Electrical) requirements.

#### **4780 Compressor Case Stators/IGVs/EGVs**

Provides the pressure shell, structural mounting rings, stators, inlet guide vanes and exit guide vanes for the compressor. As with all the other work packages in 4700, the design of the elements of this work package are highly interactive and must be designed integrally if a satisfactory machine is to be built. The design and integration of these elements must accomplish the acoustic, aerodynamic and energy efficient objectives of the LSWT and provide maintenance and operational concepts which support long term productivity and LCC objectives. Fail-operate provisions will be incorporated in all controllable surfaces to the extent practical. Fail-safe provisions are a firm requirement. All adjustable and controllable components include sufficient position indicators to record compressor configuration during all operation via the LSWT Process Instrumentation, WBS 7570. The case shall provide a compressor access maintenance door to the compressor which functionally provides access similar to the provisions in the AEDC 16S C3 and C4 Compressors. The door is required to operate at all pre and post operational shell temperatures and shall open or close in no more than 15 minutes on a routine basis. Removable hatches are required directly over the compressor bearings of sufficient size to allow bearing removal. Fixtures and tools to support bearing assembly and replacement are included.

The Compressor Case interfaces with the pressure shell at mating flanges located perpendicular to the compressor axis of rotation. The upstream flange is

a minimum of one foot upstream of the upstream edge of the upstream compressor bearing support and the downstream flange is one foot downstream of the trailing edge of the down stream compressor bearing support trailing edge. The mating surface flatness and alignment specifications shall be specified by pressure shell design of WBS 4230. The fasteners and mating hardware/seals are included in this work package.

The stators/IGVs/EGVs interface with the Nacelle, WBS 4730, at the movable interface to the fixed surface, with all mounting hardware and fittings provided by this work package. This package provides all design provisions for integration and installation of the position indicators and structural instrumentation for the components included herein. The sensors and related instrumentation for the stators, IGVs and EGVs will be provided by WBS 7570 and integrated into the LSWT Process Instrumentation System. The detailed instrumentation requirements and interface drawings are provided by this work package. Routing provisions, piping and related fittings to deliver lift and lube oil from the compressor case outer surface to the bearing housings are provided by this work package. Interfaces are the case penetrations of the bearing housings and the first physical connections outside the pressure shell or each line.

#### **4800      LSWT Electrical, Control Systems and Data Acquisition**

Data and Control Systems of WBSs 4830 and 4840 have been transferred to WBSs 7720 and 7220 respectively. The remainder of 4800 consists only of miscellaneous Electrical Equipment and Material associated with the installation of the Drive Motor and Motor Controls of WBSs 4760 and 4770 into the Wind Tunnel Drive Buildings of WBS 2200.

#### **4900      LSWT TEST AND VALIDATION**

##### **4910      Test and Validation**

The LSWT sub-systems will be tested to demonstrate performance to specified levels. The work associated with shop tests is included with individual work packages. Once installed, subsystem checkouts and integrated system tests will be performed to verify performance parameters. Test and validation hardware is provided in WBS 7000.

##### **4920      Calibration**

Components and sub-systems will be calibrated. Tunnel operational parameters such as flow quality, acoustic performance, and model data comparisons will be made. Calibration hardware is provided in WBS 7000.

#### **4A00     PRODUCTIVITY PROVISIONS**

Since production is critical to this facility, duplicate components are required in critical areas so downtime to the facility can be minimized. Any component which has a significant probability of failure, which is critical to the LSWT operation, needs to be in stock at the facility or available from a supplier, ready for immediate delivery.

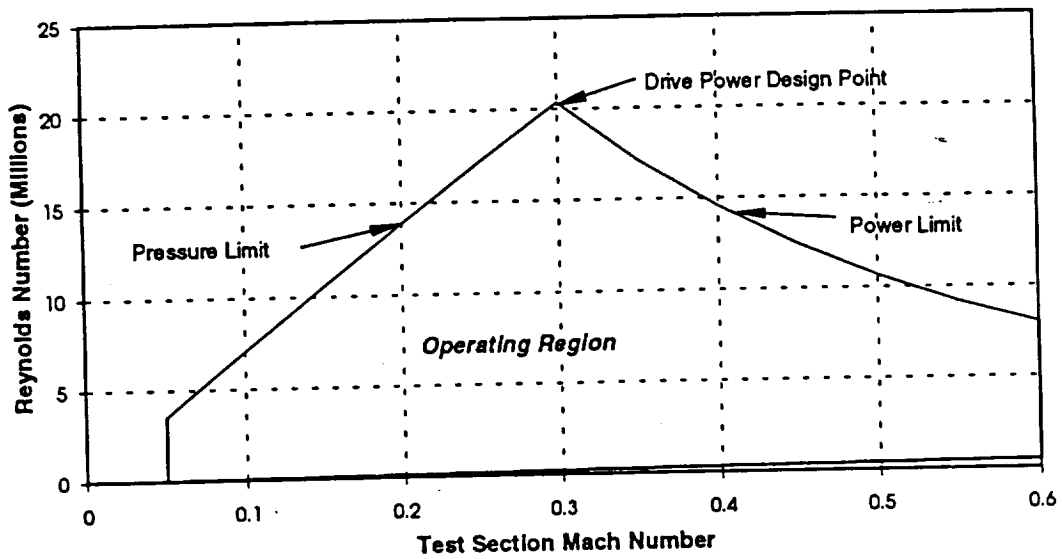


Figure 4000.a LSWT Reynolds Number Performance Curve  
 (Full Span Model, Reference Length -  $c_{bar}$  = 2.19 feet)

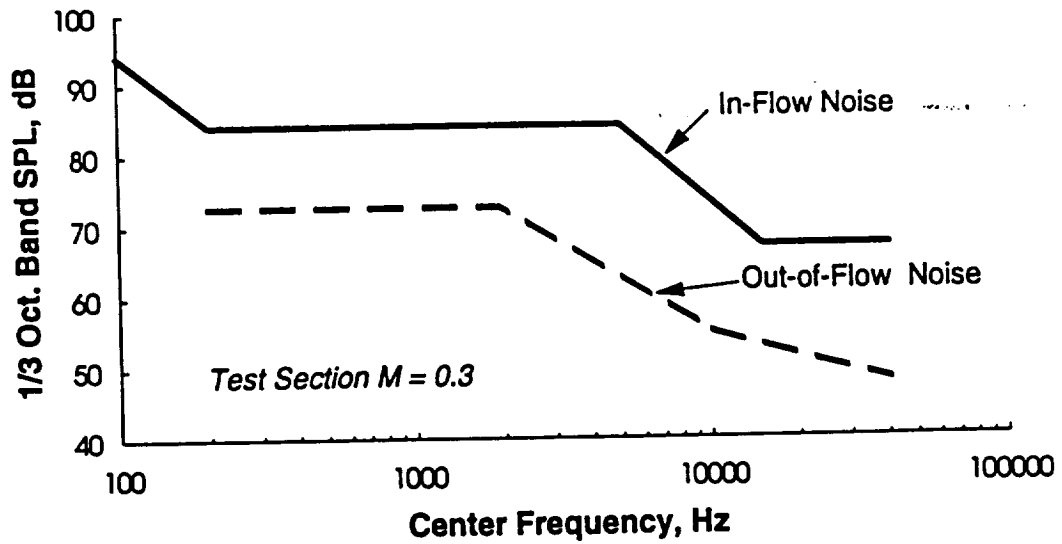


Figure 4000.b LSWT Background Noise Requirements



**Figure 4000.c LSWT Air Line Geometry**

## **5000 -TRANSONIC WIND TUNNEL (TSWT)**

The Transonic tunnel is a closed-circuit continuous-flow facility capable of providing the following ranges of test conditions:

Mach Number, (M) :  $0.05 < M < 1.5^*$  (\*Nozzle will have travel for  $M=1.6$ )  
Total Pressure, (Pt) :  $0.05 < P_t < 5$  atm.  
Total Temperature, (Tt) : Ambient to Ambient + 30F  
Reynolds Number, (Rec) :  $Rec = 28.2M$  @  $M=1.0$  (for  $c = 1.31$  ft.)

Descriptions and interfaces for the various elements which make up the transonic tunnel are presented in the following WBS 5000 level sections:

### **5100 TSWT ACOUSTIC ENCLOSURE**

#### **5110 TSWT Acoustic Enclosure Foundation**

The TSWT acoustic enclosure and pressure shell, exclusive of the tunnel compressor section, are supported on a common foundation. The foundation consists of a reinforced concrete basemat with embedded plates and bolts to facilitate the attachment of acoustic enclosure steel and pressure shell supports and anchors. The basemat is five feet thick, with plan dimensions of 455 ft x 210 ft. It is a stepped design, varying from grade level to 17.5 feet below grade. The compressor section is supported on a foundation common with the drive system, but isolated from the rest of the tunnel circuit.

#### **5120 TSWT Acoustic Enclosure**

The building surrounding the wind tunnel pressure shell is designed to reduce sound emanating from the TSWT to acceptable levels on site and at the site boundary. The building consists of a moment resisting steel space frame structure with metal siding and roofing 455 ft x 210 ft x 75 ft high. Includes personnel doorways, large access doors, and roof hatches as required for wind tunnel internal component removal. Four overhead bridge cranes, 300 ton capacity each, services the tunnel circuit, equipment and laydown space.

#### **5130 Acoustic Insulation**

Acoustic insulation lines the inner surfaces of the walls and roof and has been included in construction of the acoustic enclosure.

#### **5140 Electrical Services**

Basic building services including high bay lighting, and convenience and special purpose outlets that are located at multiple locations within the building. Data, communication, and fire alarm services are provided.

## **5150 Mechanical Services**

Fire protection provided by mobile equipment. Hose cabinets included by main access doors. Service air outlets are located at multiple locations within the building. Heating and exhaust fans are provided.

## **5200 TSWT PRESSURE SHELL**

## **5210 TSWT Support Foundation**

The foundation for the entire TSWT circuit is common with the acoustic enclosure foundation which is described in WBS 5110.

## **5220 TSWT Support Structure**

The TSWT circuit is supported above the foundation mount plates by clevis-pin connected vertical struts. The fixed-point of the TSWT circuit is located on the downstream end of the compressor, therefore, in addition to supporting the TSWT circuit all thermal expansion/contraction of the ducting must be accommodated by movement of the support structure struts.

The circuit dead weight load including all of the internals was added to the weight of water required during hydrostatic testing to size the support columns. This total load is nearly 40,000 tons.

There are 35 sets of two each support struts (70 total) for the TSWT circuit. The support struts are a welded construction of A36 carbon steel. It is assumed that the large diameter sections of TSWT ducting are situated in depressed areas such that the tunnel centerline is only 17-ft above grade. Estimates for the supports were based on an average length of 20-ft. Estimated weight for the entire lot of 70 struts is 706 tons.

Interfaces for the TSWT support structure are as follows:

- Attachment to foundation mount plates (Interfaces with WBS 5110)
- Attachments to tunnel pressure shell (Interfaces to WBS 5230)

## **5230 TSWT Pressure Shell**

The TSWT pressure shell includes all of the tunnel ducting components which comprise the pressure boundary of the TSWT circuit with the exceptions of the removeable plenum, which is included in WBS 5520, the compressor section which is included in WBS 5700 and the pressure isolation valves, which are included in WBS 5310. Additionally, the large diameter shroud which structurally supports the removable plenum/test section area between the nozzle and the diffuser inlet is included in this WBS although it is not a pressure boundary

component.

The TSWT pressure shell is designed in accordance with Section 8 of the ASME Code for Unfired Pressure Vessels. Code stamp provisions apply. Key features and performance capabilities of the TSWT pressure shell are as follows:

**Table 5230.1 TSWT Pressure Shell Description**

Parameter	Description
Design pressure range	0.07 to 5 atm minimum
Dimensions	
Flow centerline length	922 ft;
maximum ID	51 ft
Minimum ID	18.5 ft near start of first diffuser
Tunnel Centerline	Elevation 117.5 ft, (Site is 100 ft AMSL)
Contraction ratio	13:1
Internal volume	1.1 million ft <sup>3</sup>
Maximum working pressure	90 psia
Minimum working pressure	1 psia
Average wall thickness	1.15 in
Material	Welded mild carbon steel, ASME SA 516, Grade 70.
Coatings	Interior and exterior surfaces are painted
Weight	4770 tons empty

- Security: TEMPEST physical and EMI security inside plenum isolation air lock boundary.

Major interfaces for the TSWT pressure shell are as follows:

- Connection clevis to column supports at shell are part of the shell. (Interfaces with WBS 5220)
- Attachment devices (brackets) for tunnel internals are part of the shell. (Interfaces with WBS 5400)
- Auxiliary interconnects to first external flange connection are part of the shell. (Interfaces with WBS 3200,3400,& others)
- Mating surfaces (upstream & downstream) for the removeable plenum are part of the shell. (Interfaces with WBS 5520)
- Mating flanges (upstream & downstream) for the axial compressor stator casing are part of the shell. (Interfaces with WBS 5740)
- Flange connection of seal assembly for drive shaft penetration

- through shell is part of the shell. (Interfaces with WBS 5720)
- Mating surfaces for the isolation valve pressure seals are part of the shell. (Interfaces with WBS 5310)
- Support structure for isolation valves is part of the isolation valve assembly. (Interfaces with WBS 5310)

### **5300 TSWT PRESSURE ISOLATION SYSTEM**

The TSWT is equipped with isolation valves to allow the test section/plenum to be evacuated ( to ambient pressure) without depressurizing the rest of the tunnel circuit. Access to the test section for model changes is through two personnel doors in the moving plenum. This access is included in the rolling plenum WBS 5520, therefore WBS 5320 is not utilized.

#### **5310 TSWT Isolation Valves**

This element consists of two horizontal sliding gate valves, each consisting of a 2-in-thick circular-arc head with full edge flange. The valves are mounted on horizontal rail carriages and are hydraulically powered through a double rack-and-pinion drive on the sides. Salient features of the pressure isolation valves are as follows:

- Size: Upstream - 40-ft high x 65-ft long (arc length)  
Downstream - 20-ft high x 30-ft long (arc length)
- Weight: Upstream - 115 tons  
Downstream - 50 tons
- Material: Welded mild carbon steel, ASME SA 516, Grade 70
- Rating: 90 psia maximum working pressure on either side.  
1 psia minimum working pressure on either side.
- Seals: Active trapped continuous pressure seals on mating surfaces of pressure shell bulkhead in open and closed positions, Teflon seal material, pressurized dry nitrogen activated.

Major interfaces for the TSWT isolation valves are as follows:

- Support structure connections to the pressure vessel. ( Interfaces with WBS 5230).
- Inflatable seals to pressure bulkheads/surfaces (Interfaces with WBS 5230)
- Hydraulic power unit connections to drive cylinders. (Interfaces with WBS 5330)

#### **5320 TSWT Access Door**

A personnel access door is provided in the fixed part of the plenum

### **5330 Hydraulic Power Unit**

This element consists of a single hydraulic power unit for actuation of both isolation valves. The unit is located outside of the tunnel pressure vessel with penetrations to the drive cylinders. Preliminary sizing of the power unit is a 25 hp, 3000 psi system.

Interfaces for the hydraulic unit are as follows:

- Penetrations through the pressure vessel. ( Interfaces with WBS 5230).
- Electrical power from Model Installation building electrical distribution system. (Interfaces with WBS
- Hydraulic power unit connections to isolation valve drive cylinders. (Interfaces with WBS 5310)

### **5400 TSWT FLOW INTERNALS**

#### **5410 Turning Vanes**

Each 90-deg corner in the TSWT circuit is equipped with solid plate turning vanes to reduce corner losses and maintain flow quality. The turning vane cross sectional shape is designed to prevent flow separation from the turning vane itself. The trailing edges are adjustable during construction/assembly to ensure that the trailing edge flow vector is aligned to within 1-deg of the duct centerline. The turning vane assembly is designed for infinite fatigue life in the dynamic/acoustical environment anticipated in each corner.

Estimates for the TSWT turning vanes are based on solid .75-in-thick circular-arc section with trailing edge extensions. A gap-to-chord ratio of 0.4 was assumed based on past experience. The total weight estimate for the four sets of vanes, including horizontal stiffeners is 381 tons.

Major interfaces for the TSWT turning vanes are as follows:

- Turning vane attachment to pressure shell are part of shell (Interfaces to WBS 5230)
- Drive shaft penetration through corner 2 turning vanes (Interfaces to WBS 5720)

#### **5420 Honeycomb**

This element includes a honeycomb section across the 51-ft-diameter stilling chamber. The honeycomb section is part of the flow conditioning system to assure the test section cross flow quality requirements ( flow angularity,

pressure/Mach number distribution, and turbulence) are met. The honeycomb shall begin approximately 4-ft downstream of the acoustical baffles.

Estimates are based on a stainless steel honeycomb construction with length-to-diameter of 16. Cell alignment with the airstream centerline is less than 0.5-degrees.

Major interfaces of the honeycomb element are as follows:

- Attachments to pressure shell are part of the shell (Interfaces with WBS 5230)
- Penetration through contraction section liner (Interfaces with WBS 5450)

#### **5430      Screens**

This element includes 3 screen pairs installed in the 51-ft-diameter stilling chamber. The screens, in conjunction with the honeycomb and acoustic section, assure that the test section cross flow quality requirements ( flow angularity, pressure/Mach number distribution, and turbulence) are met.

Each screen set consists of a fine-mesh screen backed up by a course mesh screen. Spacing between screen pairs is 4-ft.

Major interfaces of the TSWT screens are as follows:

- Attachments to pressure shell are part of the shell (Interfaces with WBS 5230)
- Penetration through contraction section liner (Interfaces with WBS 5450)

#### **5440      Internal Heat Exchanger**

The TSWT heat of compression is removed by a folded-type, multi-bundle, air-to-water heat exchanger which is sized for the 260,000 horsepower drive. The heat exchanger will maintain a tunnel total temperature of ambient plus 30-deg F to a maximum of 130-deg F.

The heat exchanger is enclosed by the 51-ft-diameter pressure shell within a length of 51-ft. Internal fairings divert the tunnel flow through the cooling bundles and provide space for the supply and return piping. Cooling tubes are externally finned and are arranged to permit easy draining for winterization. Supply and return piping to the first flange inside the pressure vessel are included in this element. The control system for the cooler is not included in this element.

Major interfaces for the heat exchanger are as follows:

- Mounting brackets for the heat exchanger components are part of the pressure shell (interface with WBS 5230)

- Water supply/return first flanged connections inside tunnel (interface with WBS 5230)
- Instrumentation for control system is part of the process instrumentation. (Interface with WBS 7570)
- Treated water for cooling is part of the cooling water supply element (Interfaces with WBS 1330)

#### **5450 Stilling Chamber Liner**

The stilling chamber liner defines the flow contour from downstream of the acoustical baffles (5470) to the upstream edge of the test section isolation valve. The stilling chamber liner begins the internal flow cross sectional transition from circular to the 11x15.5-ft filleted rectangular test section.

The liner is a welded carbon steel construction of nominal 1/2-inch skin thickness with both circumferential and longitudinal support structure to the pressure shell.

Major interfaces for the stilling chamber liner are as follows:

- Attachment brackets for the liner are part of the pressure shell (Interfaces with WBS 5230)
- Upstream isolation valve flow surface continuity (Interfaces with WBS 5310)
- Penetrations for the flow conditioning screens and honeycomb are part of the stilling chamber liner (interfaces with WBS 5420 & 5430)

#### **5460 Plenum Evacuation System**

The plenum evacuation system (PES) is used to increase the test section Mach number by removal of mass flow from the flow stream in the test section. This mass moves from the test-section through some configuration of slotted or perforated walls in the test section wall. The mass flow is then pumped through a compressor system and reintroduced into the tunnel flow stream in the cross leg upstream of the compressor inlet (upstream of corner #2).

The PES has the capability of passing approximately 5% of the tunnel mass flow at the design point (5 atmospheres and test section Mach No. of 0.95). The PES is comprised of a suction bell mouth, an 18 foot diameter suction duct, suction isolation valve, a series of three axial flow compressors in parallel, cooling coils, a 16 foot diameter discharge/return duct, a discharge isolation valve, and the reentry annulus. The compressors are multi-stage, axial flow compressors. Each compressor is capable of passing 33% of the required flow (or all three compressors are required for 100% operation). The compressors are capable of a minimum suction pressure of approximately 0.5 psia up to a maximum suction pressure of 45 psia. The maximum compressor discharge pressure is approximately 80 psia. The compressor requires approximately 100,000 shaft

horsepower. This service will be provided from the TSWT main substation.

Each compressor discharge duct utilizes an air to water finned tube heat exchanger capable of removing the input horsepower of that compressor. The primary purpose of the heat exchanger is to remove the heat of compression.

The PES utilizes a suction duct approximately 18 feet in diameter with a radiused bell mouth type collector. The connection point for the suction, is to a fixed section of the plenum (i. e., a permanent section of the tunnel). The compressors are located external to the tunnel circuit but within the confines of the TSWT acoustic enclosure. The flow is ducted approximately 350 feet to the compressor inlet. A hydraulically actuated, high performance butterfly valve (18' diameter wafer type valve) is used as a suction isolation valve. The compressor discharge is manifolded together in a 16' diameter discharge duct, with a hydraulically actuated, high performance butterfly valve for discharge isolation. The PES system will incorporate a number of smaller lines and valves for pressure trim, blowoff, and compressor bypass. These features were not incorporated in the design as of yet.

The major interfaces for the PES system are as follows:

- Electrical power - The interface point is where the power cable is connected to the switch gear.
- Controls - The controls for initiating the PES system (i. e., turning on the compressors) will be from the tunnel control room. In addition, the integrated control of the PES, which includes the smaller bypass/blowoff systems, the number of PES compressors used, variable inlet guide vanes, etc. will come from the tunnel control room. The interface point is not clearly defined at this point. A suggested location would be a local terminal panel where the distributed control system would have a local drop that would then be connected to the various components.
- Cooling water - Cooling water is used in the cooling coils. The interface point is a flanged connection external to the duct shell. The cooling system includes the manifolding and all balancing valves. The interface points are the flange connections at the manifold inlets and outlets.
- Tunnel shell - the tunnel shell includes the bell mouth and the suction duct up to and including the upstream flange of the suction isolation valve. The tunnel shell also includes the annular reentry shell and the discharge duct back to and including the downstream flange of the discharge isolation valve (see WBS 5230).
- Foundation - The foundation includes the slab and all piles. The foundation includes a raised pad with anchor bolts. The interface point is where the component, duct, pipe support, etc., fits over the anchor bolt.

- Noise - this is a "non-contact" type of interface. The PES compressors will be the source of a large amount of noise. The adjacent structures will need to consider the addition of a large amount of acoustic insulation to minimize the noise propagation.
- Distribution system - the piping distribution system includes the vent silencers. The PES blowoff components will need to discharge into a duct somewhere (still TBD) so that the discharge can be routed through an exhaust silencer prior to discharge to the atmosphere.

#### **5470 Acoustic Baffles**

This element consists of seventeen vertical baffles uniformly spaced across the 51-ft stilling chamber just downstream of corner 4. Each baffle is 1.5-ft thick by 13-ft long with a cylindrical leading edge and tapered trailing edge. The tapered trailing edge is designed to preclude trailing edge separation. The exterior of each baffle is a perforated plate. The interior of each baffle is filled with an acoustical absorbing material.

Major interfaces of the acoustic baffles are as follows:

- Mounting brackets for the acoustical baffles are part of the pressure shell ( Interfaces with WBS 5230)

#### **5480 Contouring Nozzle**

This element is a two-dimensional flexible walled nozzle. The nozzle is 50 feet in length, with a 31-by-11-ft rectangular entrance area and an 15.5-by-11-ft rectangular exit area. The nozzle is capable of providing aerodynamic contours for establishing test section Mach Numbers up to  $M=1.5$  in 0.025 increments.

The nozzle section support structure is of welded carbon steel construction using circumferential and longitudinal members attaching to the pressure shell. The flexible sidewalls are constructed of stainless steel plates with the minimum number of jacking stations required to provide the aerodynamic contour. Based on the Ames 11-ft tunnel nozzle design it is expected that 2 to 3 jack stations will be adequate for this purpose.

Major interfaces for the contouring nozzle are as follows:

- Attachment brackets for the nozzle are part of the pressure shell (Interfaces with WBS 5230)
- Upstream isolation valve flow surface continuity (Interfaces with WBS 5310)
- Test section flow surface continuity (Interfaces with WBS 5510)
- Nozzle controls wiring attachment to the position feedback device. (interfaces with WBS 7730)

#### **5490 Compressor FOD Screens**

This element includes a protection system for the compressor from damage by foreign objects in the air stream. The system is capable of stopping large objects with impact energies up to 400,000 ft-lbs as well as small screws and nuts.

Two separate structures are provided to meet the FOD protection requirements for the TSWT compressor. A large heavy duty screen with crushable grid sections and shock-absorbing impact bolt elements is located in the downstream portion of the tunnel cross-leg between Corners 1 & 2 to "catch" large, high-energy objects. A light-duty screen is attached to the upstream side of the Corner 2 turning vane structure to stop small objects, such as bolt heads prior to entering the compressor section. The heavy-duty screen is located in a 28.5-ft-diameter ducting section.

Major interfaces for the compressor FOD screens are as follows:

- Attachment brackets to the pressure shell are part of the pressure shell (interfaces with WBS 5230)
- Light-duty screen attachments to the Corner 2 turning vanes are part of the vanes (Interfaces to WBS 5410)

#### **54A0 Choke System**

This element consists of a choke system which is installed downstream of the test section and upstream of the high speed diffuser in a constant cross sectional area. The choke system is used in the Mach number range from 0.3 to 1.0 to provide better control of tunnel conditions during model movement transients. The ancillary benefit is that the choke prevents air borne sound waves from moving up stream into the test section.

The choke system has six tapered fingers on each sidewall which extend into the airstream to varying lengths to choke the tunnel flow. Trim tabs are located downstream. This choke section includes all of the support structure to the shell.

Major interfaces for the choke system are as follows:

- Mating surface to the High speed diffuser liner (Interfaces with WBS 54B0)
- Mating surface to the test section (Interfaces with WBS 5510)
- Attachment brackets to pressure vessel are part of the pressure vessel (Interfaces to WBS 5230)

### **54B0 High Speed Diffuser Liner**

The high speed diffuser liner begins at the downstream end of the rear test section isolation valve and ends at its intersection with the pressure shell portion of the diffuser. The liner provides the transition from rectangular to circular cross section. It also contains sufficient vents to the cavity containing the isolation valve mechanism to prevent significant pressure loads across the liner during changes in tunnel pressure. The vents are incorporated so as not to contribute to diffuser separation.

The high speed diffuser liner is a welded carbon steel construction of nominal 1/2-inch skin thickness with both circumferential and longitudinal support structure to the pressure shell.

Major interfaces for the high speed diffuser liner are as follows:

- Attachment brackets for the liner are part of the pressure shell (Interfaces with WBS 5230)
- Downstream isolation valve flow surface continuity (Interfaces with WBS 5310)

### **54C0 Tunnel Cleaning System**

Six-inch penetrations for removing cleaning fluid are provided in the tunnel shell at the following locations: Stilling Chamber - downstream of the acoustical baffles, downstream of the honeycomb, downstream of each screen (Note the drains downstream of the honeycomb and screens must also penetrate the stilling chamber liner); Corners: one penetration upstream and downstream of each corner; Heat exchanger - one penetration each at the upstream, middle and downstream end; Cross leg - one penetration half way between corners 3 and 4. The inside penetration are flush with the interior surface and equipped with a cover to prevent the penetration from becoming a acoustic noise source. The exterior penetration terminates with a flange connection.

Major interfaces for the tunnel cleaning system are as follows:

- Flange connection to cleaning system (Interfaces with WBS 3610)

### **5500 PLENUM/TEST SECTION**

#### **5510 TSWT Test Section**

The TSWT test section has a cross section of 11-ft high and 15.5-ft wide. The test sections have adjustable remotely-controlled side walls to compensate for wall boundary layer growth as a function of test conditions. The TSWT is provided

with four complete test sections as follows:

**Table 5510.1 TSWT Test Section Types**

Quantity	Description	Wall type	Test types supported
2	Rear sting support strut	Slotted	<ul style="list-style-type: none"> <li>• Aerodynamic/sting mount</li> </ul>
1	Rear sting support strut	Acoustic	<ul style="list-style-type: none"> <li>• Aerodynamic/sting mount</li> <li>• Acoustic/sting mount</li> </ul>
1	External floor balance	Slotted w/ solid floor option	<ul style="list-style-type: none"> <li>• Aerodynamic full model on pod mount</li> <li>• Aerodynamic half model on turntable floor mount</li> </ul>

The test sections are automated with their own roller and drive system for installation into the moveable plenum and maneuvering within the preparation areas.

Major interfaces for the TSWT test section are as follows:

- Moveable plenum WBS 5520 (Multiple interfaces)
- Test preparations and control building WBS 2110 (Multiple interfaces)
- Nozzle exit WBS 5480, alignment of flow surface
- Diffuser choke section WBS 54A0, alignment of flow surface

#### **5520 Moveable Plenum**

The moveable plenum for the TSWT is a 38-ft-diameter cylindrical spool section which encloses the test section. The moveable plenum mates to the nozzle exit and the diffuser inlet to complete the pressure boundary of the TSWT circuit. The plenum element also includes all of the plenum internals which support the test section, including the rails on which the test section rides. The moveable plenum has an integrated electric motor driven cart system to transport between the tunnel and the model assembly building.

Requirements for productivity in the TSWT facility require that the design of this element include a full scale mock-up of the moveable plenum and interfacing components to verify the concept. In addition, a sub-scale working model will be constructed and tested to demonstrate operability of the sealing / moving techniques.

Major interfaces for the moveable plenum are as follows:

- Test section elements WBS 5510 (multiple interfaces)
- Pressure shell WBS 5230, seals on both upstream and downstream ends are part of the plenum.
- Test preparations and control building WBS 2110 (multiple interfaces)

#### **5530 Observation System**

This element consists of optical quality in-wall viewing ports and mounts for CCTV, movie and still cameras, lasers, thermographic cameras, etc. as required for monitoring TSWT test articles.

Major interfaces for the observation system are as follows:

- Video equipment provided in WBS 7220
- Mounts attach to test section elements WBS 5510
- Viewing ports are attached to the test section elements WBS 5510

#### **5540 Preparation Hall Shuttle Cart**

This element consists of a rail mounted hydraulic or electrical powered cart to transport the test section components between bays and to and from the parking area.

Major interfaces for the preparation hall shuttle cart are as follows:

- Test preparations and control building WBS 2110 (multiple interfaces)
- Test section elements WBS 5510 (multiple interfaces)

#### **5600 TSWT TEST SUPPORT EQUIPMENT**

##### **5610 Model Support**

The rear sting model support is included with the test section in WBS 5110

##### **5620 Floor Mounts**

Provisions are included for strut mounted or pod mounted models. This work element provides the interface for floor mounts only. The floor plates and turntable are provided in WBS 5110. The struts and pods are provided in WBS 7440.

### **5630 Half Model Mounts**

Provisions are included for testing of half-span models in the TSWT test section. This work element provides the interface for the floor mount only. The floor plates and turntable are provided in WBS 5110. The external balance is provided in WBS 5650.

### **5640 Stings and Booms**

(incorporated into WBS 7440)

### **5650 TSWT External Balance**

This work element consists of a pyramidal external balance with turntable. A lifting rig is provided to install the balance in the cart. Provisions are incorporated to perform the primary combined loading calibration in the cart. In addition, provisions are included to perform daily validation on each load element.

Design maximum loadings for the external balance, referenced to the center of the test section, are as follows:

- Lift 70,000 #
- Drag 25,000 #
- Side 20,000 #
- Pitching Moment 75,000 ft-#
- Rolling Moment 40,000 ft-#
- Yawing Moment 75,000 ft-#

For semi-span testing the models will be mounted on the turntable. The maximum aerodynamic loads, referenced to the test section floor are:

- Lift 70,000 #
- Drag 25,000 #
- Side 10,000 #
- Pitching Moment 75,000 ft-#
- Rolling Moment 350,000 ft-#
- Yawing Moment 75,000 ft-#

Major interfaces for the TSWT external balance are as follows:

- Attachments to the moveable plenum are part of the moveable plenum (Interfaces to WBS 5520)
- Interface for half-model mounts are covered in WBS 5630
- Interface for floor mounts are covered in WBS 5620

- Interfaces to the test section floor are part of the test section floor (Interfaces to WBS 5510)

## **5660 Other Test Support Equipment**

(incorporated into WBS 7440)

## **5700 TSWT COMPRESSOR AND DRIVE SYSTEM**

The Transonic Wind Tunnel (TSWT) Drive System provides the shaft power and the compressor produces the TSWT air flow. The primary components are the motors, motor control system, compressor (fan) and related components which interconnect these elements into the TSWT drive train. The motor feed current is provided by the yard Electrical Power System (WBS 1400). The motors, shafts/bearings/seals which interconnect the motors into a drive train for the main compressor, and the lubrication/cooling systems for the drive motors are the major components. The performance requirements, physical arrangement and characteristics of the drive system are a product of the design and will flow from the aerodynamic performance, productivity and test unit reliability specified for the TSWT complex. Common design features and interchangeable equipment shall be used to the maximum extent practical throughout the TSWT/LSWT complex. Realistic utility ramp rate control issues shall be assumed for the chosen site and Electrical Yard Design when developing the peak instantaneous drive system accelerations/deceleration in response to TSWT performance demands.

The major compressor components are the rotating and stationary compressor hardware, including the compressor case which will complete the Pressure Shell and provides the structural load path to connect the compressor to its foundation, WBS 5210. The performance requirements flow down from the TSWT aerodynamic, flow quality, acoustic and productivity requirements. The Mach number / total pressure design point will set the maximum power requirements, the maximum required Mach number condition will set the pressure ratio requirements in conjunction with the maximum required model drag and the tunnel circuit resistance. The acoustic requirements are expected to be a major factor in the compressor design.

The detailed description and interface definitions are given at the fourth tier level.

## **5710 Rotor, Hub, and Blades**

Provides the TSWT primary axial flow compressor shaft, structural mounting discs for the rotating blades and the rotating blades. The anticipated concept has fixed pitch rotor blades with the machine's variable geometry provided by the stators/IGVs/EGVs of WBS 5740. The stators are controllable with active control inputs from WBS 7730, Controls - TSWT. The IGVs and EGVs are adjustable but

are expected to be kept in a fixed configuration for most operations once the facility checkout and calibration is complete. The blade and hub design shall readily allow repair and blade replacement to support high productivity. Provides 120 % spare blades, 110% of the spares are to be manufactured after performance acceptance of the compressor installed in the TSWT.

The rotor shaft interfaces with the two journal type bearings and the thrust bearing at the surface of rotation with the rotating surfaces the boundary of this work package and the adjacent stationary surfaces included in the bearings of WBS 5720. The drive shaft and related coupling fittings of WBS 5720 will interface at the first non-removable parting surface between the compressor shaft and the motor drive train. This work package will provide five (5) instrumented blades for each row which have been calibrated to provide maximum bending and torsional stresses. The instrumentation provisions to provide four channels of strain gage data channels per row plus four additional channels of rotor data to the tunnel shell are also included in this work package and these data channels will be interfaced with WBS 7580 (Process data instrumentation) external to the compressor shell. Only limited physical interface with the nacelles and supports of WBS 5730 and the stators/IGVs/EGVs WBS 5740 are expected but seals, critical tolerances and integral design requirements for compressor performance will require extensive interface during the design and installation of the compressor. The Lubrication and Cooling (WBS 5750) requirements will be provided by 5750 with the interface point at the bearing penetrations for lift/lube oil connections.

#### **5720     Shafts/Bearings/Clutches**

Provides the drive train components which interconnect the motors (WBS 5760) and mechanically connects the motor output to the tunnel circuit fan (compressor) for the TSWT. The major components of the package are the drive train shaft segments, couplings, bearings, clutches and directly related equipment. The drive train elements are required to transmit the full overload rating of the drive system on a routine basis, but will likely be size based on maximum torque load for emergency stops and/or maximum acceleration. The couplings / clutches and mating interface surfaces are to be of common design for all motor interfaces. In addition to the hardware required to complete the drive train, a spare rotor which is physically and functionally interchangeable with any of the TSWT/LSWT main drive motor rotors is included. The drive train / coupling design is required to allow for the thermal expansion, relative movement and vibrations between the drive motors and TSWT compressor.

Eleven journal bearings and a single thrust bearing are anticipated, but the compressor design may result in a different configuration. All bearings shall be designed with slinger rings or a similar device to allow safe shutdown in the event of a lube system failure. The bearings are required to operate at the full

range of TSWT conditions without loss of oil into the tunnel. Provides 50% replacement bearing inserts, two spare bearing housings and one complete spare coupling assembly.

A turning gear system is provided on the compressor side of the motor coupling closest to the compressor. The turning gear, two speed: 1 rpm for shaft run out and 1/6 rpm for maintenance, requires sufficient torque and braking for safe operations with the maximum rotor blade imbalance configuration.

The bearings will provide the stationary surface adjacent to the rotating surfaces of the rotor WBS 5710. The lubrication and cooling for the bearings will be provided by WBS 5750 and will interface at the first physical connection point external to the bearing case. The bearing design shall integrate the instrumentation provided by WBS 7580.

The coupling / clutch interface is required to mate with the appropriate motor rotor (WBS 5760) interface surface. All needed bolts and fittings required to complete the connection with the motors and associated couplings, clutches and compressor hub shaft (WBS 5710) are included in this work package. The bearing foundations external to the tunnel shell are included in the TSWT Drive Building, WBS 2220. Lift / lube oil and related coolers interface at the penetration to the respective bearing case, with the piping and related hardware provided by WBS 5750, TSWT Lubrication and Cooling Systems. Health monitoring and diagnostic instrumentation will be provided by the Process Instrumentation work package 7580. Provisions for the integration of the WBS 7580 instrumentation will be made during the detailed design of each appropriate component of WBS 5720. The major shaft component(s) will almost certainly be the link between the bearing closest to the tunnel pressure shell and the compressor rotor hub. The seal around the shaft at the pressure shell penetration point will be included in this work package and will interface with the tunnel shell at a mating flange surface provide (WBS 5230) for this purpose.

#### **5730 TSWT Nacelles/Fairings and Supports**

Provides the aerodynamically contoured shell (teardrop shape) around the compressor hub and an symmetric airfoil fairing around the drive shaft of WBS 5720. The drive shaft fairing attaches to the pressure shell at the drive shaft penetration and extends through the turning vanes to the nacelle fairing. The primary supports of the compressor both forward and aft of the rotor blades constitute the principle load path for the compressor loads. The aerodynamic and structural requirements for these components are major factors in the compressor design effort. The required seals and directly related hardware to make the nacelle an effective aerodynamic shape are included in this package. Requirements for low turbulence and acoustic testing demand greater than normal care in the aerodynamics contouring of these fairings. The design and

fabrication approach are likely to be affected. Maintenance and accessibility require special considerations if required productivity is to be attained.

The rotating portions of the nacelle attach to the rotor shaft and the interface is at the removable joint closest to the center of rotation with all fasteners provided with the fairings under this work package. The non-rotating portion of the nacelle will attach to the supports and provide the center body attachment for the stators/IGVs/EGVs of WBS 5740. The interface with movable or adjustable components will be at the removable joint which separates the movable surface from the stationary elements. All stationary surfaces and mounting provisions are included in this package and all movable hardware and related fittings and fasteners are provided by WBS 5740.

The supports which provide the primary structural load path for the compressor loads interface with the pressure shell, WBS 5230 at the contour intersection between the two components unless the structural and fabrication approach indicate a more logical interface. The rotor end of the supports interfaces at the mating surface for the rotor bearings. The attachment provisions for the bearings are included herein and all fasteners and fittings are provided by WBS 5720.

The shaft fairing will interface with the pressure shell, WBS 5230 and turning vanes, WBS 5410 at the contour intersection between the two components unless the structural and fabrication approach indicate a more logical interface.

#### **5740 Compressor Case Stators/IGVs/EGVs**

Provides the pressure shell, structural mounting rings, stators, inlet guide vanes and exit guide vanes for the compressor. As with all the other work packages in 5700, the design of the elements of this work package are highly interactive and must be designed integrally if a satisfactory machine is to be built. The design and integration of these elements must accomplish the acoustic, aerodynamic and energy efficient objectives of the TSWT and provide maintenance and operational concepts which support long term productivity and LCC objectives. Fail-operate provisions will be incorporated in all controllable surfaces to the extent practical. Fail-safe provisions are a firm requirement. All adjustable and controllable components include sufficient position indicators to record compressor configuration during all operation via the TSWT Process Instrumentation, WBS 7580. The case shall provide a compressor access maintenance door to the compressor which functionally provides access similar to the provisions in the AEDC 16S C3 and C4 Compressors. The door is required to operate at all pre and post operational shell temperatures and shall open or close in no more than 15 minutes on a routine basis. Removable hatches are required directly over the compressor bearings of sufficient size to allow bearing removal. Fixtures and tools to support bearing assembly and replacement are included.

The Compressor Case interfaces with the pressure shell at mating flanges located perpendicular to the compressor axis of rotation. The upstream flange is a minimum of one foot upstream of the upstream edge of the upstream compressor bearing support and the downstream flange is one foot downstream of the trailing edge of the downstream compressor bearing support trailing edge. The mating surface flatness and alignment specifications shall be specified by pressure shell design of WBS 5230. The fasteners and mating hardware/seals are included in this work package.

The stators/IGVs/EGVs interface with the Nacelle, WBS 5730, at the movable interface to the fixed surface, with all mounting hardware and fittings provided by this work package. This package provides all design provisions for integration and installation of the position indicators and structural instrumentation for the components included herein. The sensors and related instrumentation for the stators, IGVs and EGVs will be provided by WBS 7580 and integrated into the TSWT Process Instrumentation System. The detailed instrumentation requirements and interface drawings are provided by this work package. Routing provisions, piping and related fittings to deliver lift and lube oil from the compressor case outer surface to the bearing housings are provided by this work package. Interfaces are the case penetrations of the bearing housings and the first physical connections outside the pressure shell or each line.

#### **5750      Lubrication and cooling systems**

Provides the lift/lubrication and cooling systems for the rotor bearings and main drive motor bearings of the TSWT. Water to oil heat exchangers for bearing lift/lube systems are included, as well as the related components needed for control and safety provisions. The design to properly size and locate the required equipment shall consider the LCC of maintenance and operations as well as the trade studies for construction cost. To the maximum extent practical, the components and subsystems used throughout the TSWT/LSWT complex shall be of common design and interchangeable. To facilitate maintenance and handling functions, the equipment included in this work package will be located below the main drive motor floor level. Cost / design trades are to determine the merits of large central systems versus smaller distributed subsystems through out the complex both LCC and reliability requirements must be included. High value equipment protection and reliability of total system performance are the major design requirements.

The bearing lift and lubrication systems and related heat exchangers, controls and pumps interface with the bearings at the physical connection closest to the bearing case/housing. All piping and fittings are included in this package. Electrical power and cooling water will be provided to all equipment in this work package by appropriate distribution systems in WBS 2220. The installation wiring and plumbing is included in this work package for the connection of these systems

to normal distribution points for electrical and cooling water utilities in the TSWT Drive Building, WBS 2220. Design requirements for equipment size, access and utilities will be input to the requirements of WBS 2220. Design loads for the cooling and lubrication requirements will be input from WBS's 5760 and 5720 and cooling loads will be input to WBS 3400, Cooling System. The required equipment includes 25% spares for pumps, valves and controls which are common to all similar systems.

Unless impractical, the journal bearings of WBS's 5760, 5720, 4720 and 4760 are all required to be physically and functionally interchangeable.

### **5760 Motors**

The motor sizing and design are defined by the TSWT performance requirements and projected compressor design performance. The design continuous duty rating shall be 1.05 of the projected required shaft horsepower rating needed for the TSWT design point performance. An intermittent duty cycle is required at 1.20 times the continuous duty cycle level for up to one hour with a one hour synchronous speed cool down at or below the continuous duty cycle maximum power level. All TSWT motors shall be of common design, physically and functionally interchangeable. Major components should be interchangeable to the extent practical based on Life Cycle Cost considerations.

The motor drive system shall be able to deliver at least 75% of peak power to the TSWT on a continuous duty cycle with one motor removed for major maintenance or repair. The motor, drive shaft, building and support equipment shall provide the ability to remove any main drive motor from the TSWT Main Drive Train and install a replacement motor to reestablish drive capability within 24 hours.

The motors interface with the Motor Controls (WBS 5770) at the closest physical connection point to the motors. The electric requirement specifications are quoted for that interface point. The drive motor foundations are included in WBS 2220, TSWT Drive Building. Cooling air provisions for the motors are required in the design of these foundations. The motor bearing lubrication and related cooling are provided by WBS 5750 with the interface point at the motor housing penetration/flange. The rotors will interface to the drive train components (WBS 5720 Shafts/Bearings/Clutches at the parting surface of a coupling flange at both ends of the rotor shaft. A common flange configuration is required for all drive motor couplings. The coupling hardware (bolts, pins, etc.) are included in the WBS 5720 definition. WBS 5720 includes a journal type bearing to support each end of the rotor shaft. The interface surface is defined as the surface of rotation, i.e. the rotating shaft is part of the motor and the stationary bearing surface is included in the bearing package.

**5770 Motor Controls**

Provides the variable frequency start system and sub synchronous speed control system for the TSWT Main Drive Motors, WBS 5760. The major components of the system includes the switch gear, harmonic filters and redundant power conditioning and directly related equipment. A major portion of the equipment will be located outdoors in the Station No. 1 area adjacent to the 138/13.8 kV conversion equipment of WBS 1400. All equipment must be provided with its own weather protection and sufficient environmental conditioning provisions to ensure reliable operations and most economical LCC. The primary design requirement is to accelerate to any desired speed above 5% of synchronous speed and maintain that speed  $\pm 1$  rpm indefinitely. The total drive train is required to accelerate to any demand speed in two minutes or less and stabilize at the demand speed within 10 seconds.

The Motor Controls system receives input power from the power conversion equipment in the Yard Electrical Power System, WBS 1400. The 13.8 kV input interfaces at the first physical connection point inside the initial enclosure(s) for the equipment in this work package. The output interface is the physical connection to the motors nearest the motor case/housing. All interconnections within and between elements of the Motor Controls equipment are included as part of this work package. The demand/set point control input to this equipment comes from WBS 7700 and the signal will be to the appropriate location for input to this equipment. Concrete pads for the installation of the Motor Controls system equipment are included in the WBS 1400 (Yard Electrical) requirements.

**5780 Gearboxes**

The current concept does not require any TSWT Main Drive Train gearboxes.

**5800 TSWT ELECTRICAL CONTROL SYSTEMS AND DATA ACQUISITION**

Data and Control Systems of WBS 5830 and 5840 have been transferred to WBS 7730 and 7230 respectively. The remainder of 5800 consists of miscellaneous Electrical Equipment and Materials associated with the installation of the Drive Motor and Motor Controls of WBS 5860 and 5870 into the Wind Tunnel Drive Buildings of WBS 2200.

**5900 TSWT CHECKOUT AND VALIDATION**

The checkout and validation of the TSWT encompasses integrated system checkout through facility calibration phases. Sub-system and system level component checkouts are accomplished as part of the respective component WBS elements. Beginning with the integrated system checkouts, accomplishment of the TSWT checkout and validation phase provides a usable production test

facility ready for customer testing.

#### **5910 Checkout**

The TSWT checkout is initiated when all of the system-level component checks have been completed and any significant deficiencies, identified in the process, have been corrected. An Integrated Systems Review (ISR) will be conducted to validate readiness prior to initiation of the integrated system testing of the TSWT facility. The integrated system testing matrix shall include operation of the facility to the boundaries of the performance envelope to determine/document the safe limits of the facility operation. A tiered approach to integration of the system testing requirements will be utilized to ensure equipment/personnel safety during checkout.

A comprehensive checkout plan which describes the required elements of TSWT integrated system testing will be prepared as part of this work element.

Correction of significant deficiencies identified during the checkout phase are not part of this WBS element, however required activities such as tuning of control systems and minor equipment adjustments are included.

#### **5920 Validation/Calibration**

Validation/calibration of the TSWT facility includes the activities associated with the measurement of the test section flow parameters over the range of facility test conditions to (1) validate compliance to requirements (flow quality, performance, etc.) and (2) provide a basis for the development of the test section calibration. This work element includes all labor, materials and utilities required to conduct the TSWT validation/calibration from planning through calibration.

An Operational Readiness Review (ORR) is conducted prior to the initiation of validation/calibration testing in the facility. The ORR provides a comprehensive assessment of the facility, equipment, procedures, staffing and overall readiness for initiation of validation/calibration testing.

Consistent with the checkout phase, deficiency correction other than minor tuning, is not included in this work element.

#### **5A00 PRODUCTIVITY ITEMS**

This work element provides all of the equipment required to maintain the productivity of the TSWT facility during normal operations. The equipment will include all of the routinely replaced parts which can fail and must be available for rapid replacement.

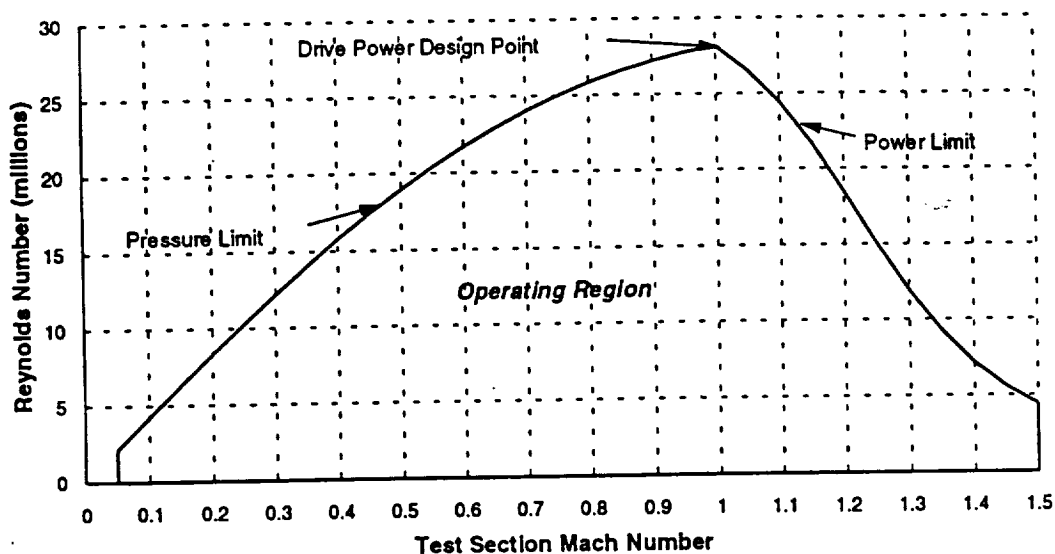


Figure 5000.a TSWT Reynolds Number Performance Curve  
(Full Span Model, Reference Length -  $c_{bar} = 1.31$  feet)

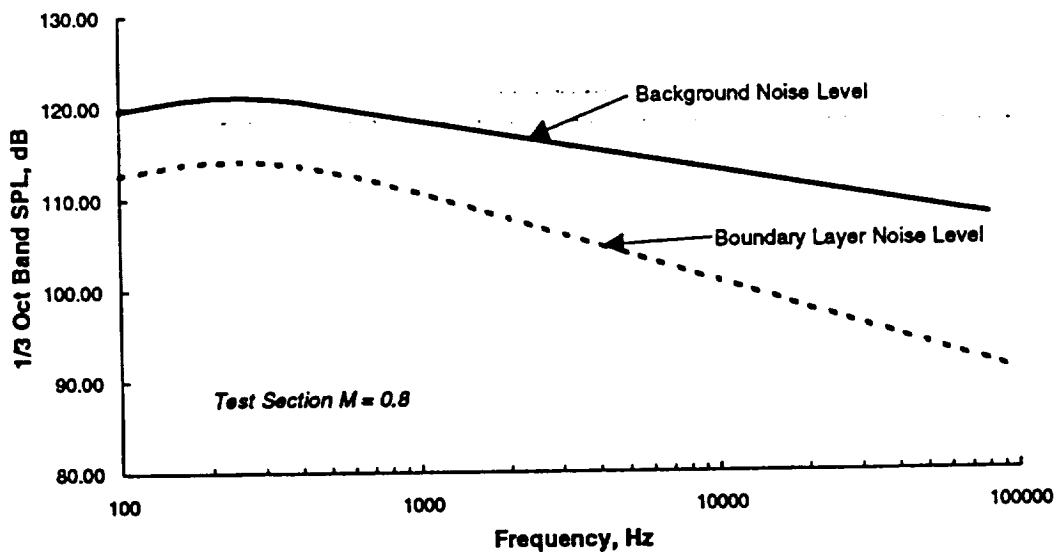
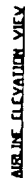


Figure 5000.b TSWT Background Noise Requirements



**Figure 5000.c TSWT Air Line Geometry**

## 7000 OPERATIONS (LSWT/TSWT)

### 7100 CALIBRATION

The site shall have the capability to systematically functionally check and calibrate, as required, in a hierarchical manner beginning with each functional component and proceeding to each subsystem assembly and final complete system/facility calibration. Performance and uncertainty standards shall be contained in the individual component/system specifications.

#### 7110 Auxiliary Process System Calibration

Auxiliary process systems consist of the high pressure air system, tunnel pressurization system, tunnel vacuum system, and heat exchanger system. Each of these systems will be functionally/performance verified during shakedown/checkout of each system. No special hardware or instrumentation to perform such checks are anticipated. Process instrumentation for the auxiliary systems is included in WBS 75B0.

#### 7120 Airflow Calibration Laboratory

The airflow calibration lab shall house the equipment and capability to calibrate blowing nacelles, engine simulation nozzles, turbine powered simulators, and inlet ducts for mass flow, thrust, and drag at conditions duplicating the static pressure environment of the tunnels. An air source of up to 40-lb/sec at 3000 psi and 400°F regulated down to 0.2-lb/sec, 5 psia, 80°F shall be provided. The air lab shall also contain instrumentation and data reduction equipment to completely calibrate each device and process the calibration data to produce a calibration algorithm for each device. The data process computer shall be connected by LAN to the tunnel data reduction computer in order to electronically download the calibration algorithm.

Interface: 7120 interfaces with 3200 which supplies high pressure air and vacuum (It may be wise to provide an independent vacuum source for this lab), with 7200 which provides the instrumentation, process-control/data-acquisition/data-processing computer and LAN connection.

Assumption: The airflow calibration chamber shall be capable of holding pressures ranging from 5-atm to 1-psia and contain airflow and force measurement systems. Assume the outside chamber dimensions to be 6-ft diameter, 18-ft long with two internal bulkheads. The first bulkhead isolates the inlet flow from the inlet-plus-jet/turbine flow and contains the mounting structure, six component balances (2), high pressure air piping to the device being calibrated, pitching moment counter-balance, and force isolation bellows for the device under test. The upstream portion of the chamber contains penetrations

and flow conditioning screens to provide inlet flow to the devices. The second bulkhead contains calibrated venturis sized in geometric progression to accommodate the mass flow range requirement. Flow conditioning devices are contained between the two bulkheads to provide undisturbed flow entering the venturis. Two airflow regulation systems are required. The first supplies relatively low pressure, ambient temperature air to provide inlet flow to the device being calibrated (TPS, inlets, etc.). The second regulates the high pressure, heated air which drives the TPS turbines, supplies the blown nacelles, or supplies the engine simulation nozzles.

Inlet air will be supplied to the simulator, nozzle, etc., through a bell mouth that incorporates variable exit areas and flow conditioning screens. The pressure vessel is pressurized from a facility high pressure air source while the low pressure in the exit chamber may be created with high pressure ejectors inside venturis. The high pressure air ejectors would also be driven by facility high pressure air and, with the venturis, comprise the air ejector vacuum system. The model is mounted, by a common flange, to a model support frame, which is, in turn, mounted to a pair of balances. The balances will be stiff in the normal force direction, to support the model's weight, but relatively weak in axial force to allow for precise measurement of drag and thrust. All air will be transferred across metric breaks with bellows arrangements. The entire balance mount and compensation bellows assembly will be contained in the pressure vessel, with access doors and windows included in the facility. The pressure vessel will have at least one large flange joint (equal to the major diameter of the vessel) at or near the model mounting location, to allow for model installation and removal of the model mount and compensation assembly for servicing. In the event of a turbine powered simulator failure, the pressure vessel may experience a rise in internal pressure and will, therefore, include pressure relief valves or a rupture disk.

#### **7130 Balance Calibration Lab**

The balance calibration lab will provide the equipment necessary to accurately calibrate all strain-gage balances and force transducers that will be run in the LSWT and the TSWT. In addition, the lab shall also accommodate and contain the equipment for calibration of hinge-moment, wing bending, fin load, etc., gages. It is intended that the primary calibration of the external balances be accomplished in the carts at infrequent intervals, but the balances will be provided with automatic check-calibrate load cells for daily calibration verification. The external balance load cells shall be calibrated in the balance calibration lab with dead weights or by a certified outside meteorological lab. Cost estimates include two automatic calibration machines, two manual calibration stands, and associated support hardware. Expense of the automatic calibration machines can greatly vary depending on the type and quality of the systems. Included estimates are based on state of the art, high quality machines. One automatic calibration

machine will provide the following load capacity:

Lift	±81,000 lb.
Drag	±18,000 lb.
Side	±7,000 lb.
Pitching Moment	±41,000 ft-lb.
Rolling Moment	±37,000 ft-lb.
Yawing Moment	±19,000 ft-lb.

These loads satisfy the maximum expected aerodynamic loads for internal balances in either wind tunnel. However, a large majority of tests will not reach these loads. Therefore, the second automatic calibration machine was estimated with the reduced load capacity listed below.

Lift	±20,000 lb.
Drag	±12,000 lb.
Side	±7,000 lb.
Pitching Moment	±25,000 ft-lb.
Rolling Moment	±20,000 ft-lb.
Yawing Moment	±19,000 ft-lb.

The automatic calibration machines will provide good accuracy ( $>0.1\%$  of load), excellent repeatability ( $>0.01\%$  of load), and timely calibrations ( $<8$  hours for 1000 combined loadings). However, dead weight calibrations performed in the manual calibration stands will provide the greatest accuracy. Both stands could be used to calibrate internal balances for test purposes or for use as the standards for the automatic calibration machines. The large stand may also be used to calibrate the external balances that are mounted on movable carts. The large stand would be designed for the following load capacity:

Lift	±115,000 lb.
Drag	±24,000 lb.
Side	±20,000 lb.
Pitching Moment	±94,000 ft-lb.
Rolling Moment	±840,000 ft-lb.
Yawing Moment	±118,000 ft-lb.

The small manual stand would have the same load capacity as the large automatic calibration machine. Associated support hardware contains items such as: calibration fixtures, adapters, thermal test equipment, overhead crane, forklift, signal conditioning and data systems, actuators, hangers, levels, inclinometers, optical alignment equipment, hand tools, ring and plug gages, taper gages, surface table, dial indicators, verniers, gage blocks, microscope, and storage cabinets.

It should be noted that dead weight calibrations are the most accurate calibration method and therefore the method used for cost estimation. However, dead weight calibrations are time consuming. An alternate method would be to use hydraulic actuators and load cells in place of the dead weights. This method could be semi-automatic and thus reduce the time of a dead weight calibration. Concerns would include increased structural capacity where the hydraulic actuator is grounded, and diminished accuracy due to load alignment and vibrations input from the hydraulic system or the actuator ground. Costs of a hydraulic system should be comparable to a dead weight system.

#### **7140      Structural Calibration Lab**

This laboratory will contain necessary equipment to support modal analysis of test models in the assembly bays.

#### **7150      Instrument Calibration Lab**

This facility will provide the service, repair, and calibration support for measurement and control instrumentation utilized by the LSWT and the TSWT. The calibration services shall include the disciplines of force, force balance, strain, pressure, anemometry, skin friction, acceleration, vibration, temperature, infra-red, humidity, acoustics, dimensional, voltage, current, resistance, capacitance, frequency and time. Repair services for the majority of the electronic and physical instruments required in these facilities shall be accomplished in this laboratory. This Instrument Calibration Laboratory shall be automated to the maximum extent possible ranging from control of the calibration standards and acquisition and analysis of the instrument data to electronic transfer of all instrument calibration to the major computer used to analyze the wind tunnel data and to operate the facilities. This laboratory shall function such that the measurement uncertainty of all wind tunnel measurements shall have traceability to accepted national standards or procedures and conform to requirements of national calibration laboratory documentation such as MIL-STD-4566A and the International Standards Organization 9000 series.

#### **7160      LSWT Calibration Hardware**

An instrumented centerline pipe, mounted to the model support roll mechanism or the dummy strut, depending on which model cart is being calibrated, and extending forward to a cable mounting system will be used in the determination of flow quality. Instrumentation requirements are pressure orifices top and bottom spaced every six inches, to TS 0.00, and one foot increments through TS -14.0. The pipe will have the capability to be indexed 0.5 ft axially. Additionally, a rake that can be mounted to the roll coupling and/or the traversing pitch strut will be used at various test section stations to further survey the flow quality in the test section. The rake will have a traversing arm moving normal to the flow from the

tunnel centerline to within one foot of the wall, with 360 degree roll capability. The arm will have provisions for simultaneous measurement of local  $P_t$ ,  $P_s$ , , , dynamic total pressure,  $T_t$ , and turbulence. Fixed rakes will also be provided to measure the average boundary layer properties on each wall.

#### **7170. TSWT Calibration Hardware**

An instrumented centerline pipe, mounted to the model support roll mechanism or the dummy strut, depending on which model cart is being calibrated, and extending forward to a cable mounting system will be used in the determination of flow quality. Instrumentation requirements are pressure orifices top and bottom spaced every six inches, to TS -11.0, and one foot increments through the nozzle throat. The pipe will have the capability to be indexed 0.5 ft axially. Additionally, a rake that can be mounted to the roll coupling and/or the traversing pitch strut will be used at various test section stations to further survey the flow quality in the test section. The rake will have a traversing arm moving normal to the flow from the tunnel centerline to within one foot of the tunnel walls, with 360 degree roll capability. The arm will have provisions for simultaneous measurement of local  $P_t$ ,  $P_s$ , , , dynamic total pressure,  $T_t$ , and turbulence. Fixed rakes will also be provided to measure the average boundary layer properties on each wall.

#### **7180 Calibration Model (LSWT & TSWT)**

The calibration model will be used for initial Low and Transonic Speed Wind Tunnel checkout and acceptance, and for periodic diagnostics over the life of the tunnel. The calibration model configuration will be such that an established database exists for comparison, or there will be a requirement to test the calibration model in an existing facility to establish a database. The model will incorporate a moderate level of pressure instrumentation ( $\approx 200$  pressures), a standard health diagnostic package (including, but not limited to, accelerometers and on-board AOA transducers), an internal balance mount and on-board analog-to-digital processors for all output. The material is assumed to be stainless steel due because of the expected loads and the duration of expected service.

#### **7190 External Balance Calibrator**

This device will provide the ability to calibrate the LSWT and the TSWT external balances. Definition of the Calibration cannot be made pending external balance design. At issue is external balance grounding structure and permanence of the external balance attachment to the model carts.

**7200 DATA ACQUISITION SYSTEM**

**7210 Data Acquisition System - Auxiliary System**

Equipment provided in WBS 7220 and 7230

**7220 Data Acquisition System (LSWT)**

**TEST DATA SYSTEMS**

**TUNNEL PARAMETER DATA SYSTEM** - This system acquires data from various locations around the tunnel circuit. Measurements are predominantly temperatures, dew point, pressures, and positions needed for test or control functions. This system acquires the data, computes engineering units and coefficients, performs some limit checking and alarming, and makes the data available via high speed networks to the tunnel control and facility management processors. Trend and historical performance data are archived for later analysis. Data is also passed to the data acquisition control processor for synchronization with the test data and for real-time display.

**DATA ACQUISITION CONTROL PROCESSOR** - This system acquires test measurements from the test section or a cart bay area and the tunnel parameters processor. Data is acquired from the test section or cart area via a high speed fiber optics network from processors on the model cart. Information from the test section is synchronized with the tunnel parameter information, reduced to engineering units and coefficients, and passed through high speed networks to other data processing, analysis, and control systems. This processor also provides real-time display to the data acquisition system operator's console. This processor handles the sequencing of all data acquisition related processes when commanded by the operator or by the facility management processor and when test conditions are achieved. This processor also alerts the facility management processor when data has been acquired so that test conditions can be set for the next test point.

**DATA PROCESSING WORKSTATIONS** - These workstations receive test data for the data acquisition processor via a high speed network. This data is then processed in near real-time for the test engineer's test console as well as other stations. Data will be represented through a high end graphical user interface that will present data in a flexible, easy format that can quickly be changed by the engineer.

**DATA ANALYSIS WORKSTATIONS** - These workstations will have high end graphics capability to provide near real-time quality graphics that can be readily compared with previous test conditions stored on the data archive file server. These displays will be located near the test engineer's console and can be

networked to the data analysis rooms.

**DEVELOPMENT AND SIMULATION** - These processors are available to support development and operations functions without interfering with the daily operations of the tunnels. Functions that will be supported include data acquisition systems software development, controls systems software development, simulation, documentation support, hardware and software system checkout, test preparation, and software configuration control. One processor will be provided for DAS support, one for controls, and a small file server for documentation and administrative services. These computers will also be configured in such a fashion that they can serve as backup processors for other processors on the control room network.

**DATA ARCHIVE FILE SERVERS** - This processor will be the repository for test data as it is being acquired. Tunnel process control data will also be archived on a separate server for post test analysis. Previous test configuration data or theoretical predictions will reside on this archive system so that they may be called up for analysis and comparison with the current test. Files will be maintained in a secure environment to provide access only as required. Optical disk storage will be provided for archiving large volumes for static and dynamic data, and high speed printers will be provided.

### **DATA ANALYSIS ROOMS**

Two rooms will be provided adjacent to the main control room for use by visiting test personnel during preparation, testing, and limited post test analysis. Both areas will be networked to the cart areas, the test section, and the main control room; however, each data analysis room will be capable of isolation for classified tests so that only appropriate networks are active to support setup in a model preparation area or test section. Each analysis room will have a file server for data archiving and analysis as well as several workstations and X terminals to support real-time data display, and analysis during setup, calibration, and checkout prior to tunnel entry. Video projection systems will also be provided for displaying real-time or video from the test section.

**COMMUNICATIONS** - Since the system architecture uses a tiered, distributed system approach, communications networks will play a key role during systems operations. It is anticipated that high speed fiber optics networks will be used extensively throughout the system. The proposed system will offer support for LAN/Ethernet 802.3, FDDI, IEEE 488, RS 232/422, reflective memory fiber optic systems, and other technologies appropriate at the time of construction.

### **CART INSTRUMENTATION SYSTEMS**

**TEST INSTRUMENTATION CART** - Each test cart contains a completely stand

alone integrated data acquisition and control system. It is anticipated that the system will rely heavily on emerging VME, Futurebus, and VXI technology. A lower level control and data bus will be provided so that various systems on the cart will have access to the same transducer inputs for control functions as well as test measurements, where practical. Data will be patched from the model to a patch panel for easy model setup and checkout. A fiber optics network link will also be provided to the model for any on-board instrumentation. Signal conditioning will be provided by this data system or, in some cases, by ancillary equipment for unique instrumentation. A higher level local area network (LAN) fiber optics communications bus connects the various processors on the cart to allow exchange of processed information. The static DAS, the dynamic DAS, and model attitude control systems will remain as permanent systems on the cart, but additional systems to provide model engine simulator or high pressure air control, model surface control, probe control, or acoustic dynamic data acquisition can be installed as required. When these systems are added to the cart, they are connected to the data bus and inter-processor LAN communications bus which allows them to be integrated and controlled by software. Workstations and X terminals connect to the LAN to support the cart in the model build-up bay area. All calibration, model attitude, model engine simulator or high pressure air operation, model surface movement, hook-up and checkout can be accomplished with the data and control systems on the cart; however, a fiber optics network will connect the cart to either data analysis room for customer checkout before moving the cart to the tunnel. Power will be maintained on the cart during movement to the test section to maintain constant cooling to the analog equipment so as not to affect calibration coefficients or require a prolonged warm-up period.

**TEST STATIC DATA SYSTEM** - This system acquires data from the test model, the model support systems, and other areas adjacent to the test section. Full software support is included for signal conditioning, system calibration, system diagnostics, conversion of data to engineering units and coefficients, and driving of real-time display systems for the technicians during model set-up and calibration. Appropriate data is also passed to the on-cart model attitude control system for command and control of the model attitude, model engine simulators, and model surfaces. This system also synchronizes and controls the electronic pressure scanning system for acquiring up to 2000 ports of pressure data. Up to 256 channels of analog data will be acquired and 24 channels of digital information. Digital information will include binary, BCD, Datex code, resolver inputs, and special instruments requiring RS 232 or IEEE 488 protocol. When the cart is moved to the test section, a single X terminal will be used to perform any required diagnostics through the data processor for final checkout. The cart will then be connected by a fiber optics LAN to the central control room where command and control will be conducted during the test.

**DYNAMIC PRESSURE DATA SYSTEM** - The dynamic pressure data system will acquire data from up to 80 channels of dynamic pressure instrumentation. It is

anticipated that this system will have an analog to digital converter per channel with up to 10 megabytes of buffer ram per channel. Data will be dumped to high speed 20 Gigabyte removable disks for archiving. The control processor will support a graphical signal analysis package with the cart and will be controlled from the central control room during tunnel testing. Each channel will have programmable gain and filter setting with appropriate signal conditioning for the transducers. The system will acquire data at up to 100 KHz per channel.

**HOT WIRE ANEMOMETRY DATA SYSTEM** - This system will record data from special signal conditioners utilizing constant temperature and constant current controllers for hot wire and hot film sensors. In addition, 24 channel of microphone data will also be provided. This system is used to measure hot wire and hot film anemometry instrumentation mounted directly on the model or in the tunnel air flow areas. One complete system will be provided for each cart for both the LSWT and the TSWT. The system is composed of the following components:

- Sensors
- Surface Mounted Hot Film Anemometer CTA System
- Hot wire/Film Probe Anemometer CTA/CCA System
- Signal Conditioner AC/DC Splitter
- Static DAS (for reading DC component)
- Transient Data Recorder(TDR) DAS 100 KHz
- Transient Data Recorder(TDR) DAS 1.25 MHz
- Anemometer DAS CPU
- Anemometer DAS Workstation

**Sensors** - Two types of sensors are used, the constant temperature anemometer(CTA) and the constant current anemometer(CCA) hot wire probes and hot film. In addition, 24 microphones will be employed to acquire acoustic data at rates up to 100 KHz.

**Surface Mounted Hot Film Anemometer CTA System** - The sensing units are powered and signal conditioned by a multi-channel anemometer system which provides computer control of calibration, gain, offset, and filtering. The output signal bandwidth is DC to 40 KHz and the output amplitude is 5 to 15 VDC and 1 to 750 millivolts AC.

**Signal Conditioner AC/DC Splitter** - The analog output signals from the anemometer system are input to the signal conditioner units. These multi-channel units buffer the incoming signal to two outputs. One output is AC coupled and one output is DC coupled. The AC coupled output amplifier will block the DC signal component and provide selectable gain to drive the maximum of 10.24 volts into the TDR. The DC coupled output amplifier will provide both gain and attenuation settings to drive or limit the maximum signal of 10.24 volts into the Static DAS.

**Anemometer Static DAS** - The Static DAS system consists of 80 channels of voltage inputs from the signal conditioner AC/DC splitter units. The Static DAS has programmable low pass filter and auto-ranging gain capability. The selectable filters will filter out the AC component of the anemometer signal. The channels, gains, and filter selection will all be contained in a scan table that resides in the DAS unit. The scan rate will also be programmable. The unit will provide self calibration and correction capability.

**Transient Data Recorder (TDR) DAS 100 KHz** - The TDR provides high speed sampling and recording of multiple analog inputs at data rates up to 250 KHz. Sampled data are stored in 10 MB of on-board DRAM for each analog channel. The data is off loaded between runs through a high speed data bus and to disk. The unit features a 16 bit analog to digital converter with input gain and low pass filtering. Unit calibration is accomplished using an external voltage calibration standard. Software and hardware features support system calibration. Several methods of triggering will be available, including program control, external logic signal, and analog level detection on one channel. Twenty four additional channels will be provided to acquire microphone data.

**Transient Data Recorder(TDR) DAS 1.25 MHz** - The TDR provides high speed sampling and recording of multiple analog inputs at data rates up to 1.25 MHz. Sampled data are stored in 10 MB of on-board DRAM for each analog channel. The data is off loaded between runs through a high speed data bus and to disk. The unit features a 16 bit analog to digital converter with input gain and low pass filtering control. Unit calibration is accomplished using an external voltage calibration standard. Software and hardware features support system calibration. Several methods of triggering will be available, including program control, external logic signal, and analog level detection on one channel.

**Anemometer DAS CPU** - The Anemometer DAS CPU will act as the host for controlling the data acquisition with the Anemometer Static DAS, the TDR 100 KHz and the TDR 1.25 MHz. The calibration calculations and engineering units conversion will also take place in the DAS CPU. The DAS CPU will put the converted data out on the local area network as well as storing it on a local hard disk. A graphical user interface package will be provided to control the acquisition process.

**Anemometer DAS Workstation** - The DAS workstation will act as the operator interface for the entire anemometer system. The local area network will provide the link between the anemometer DAS CPU and the workstation. The programming and scan list creation, scan initialization, synchronization

and semi-real time graphical display of the resultant data will all be functions of the workstation. Software to run FFT's and perform other signal analysis on the data will also be available. The operator interface software will be a standard Windows compatible off the shelf package with enhancements.

**ACOUSTIC RAKE SURVEY DATA SYSTEM** - One high speed dynamic acoustic data system will be provided for the LSWT with an identical system being provided for the TSWT. The system will acquire data from up to 256 channels, 16 of which will be microphone data recorded up to 250 KHz per channel. the remaining 240 channels will be recorded at 50 KHz per channel. The system is anticipated to have a 16 bit analog to digital converter per channel with 10 million words of buffering per channel. Data will then be dumped to high speed disks. A data acquisition computer will be provided to allow signal analysis during set up and, from the control room, during testing. In addition, an acoustic survey wing will be controlled to acquire data during a survey of the noise field. An identical system will be provided for the TSWT.

#### **7230 Data Acquisition System (TSWT)**

### **TEST DATA SYSTEMS**

**TUNNEL PARAMETER DATA SYSTEM** - This system acquires data from various locations around the tunnel circuit. Measurements are predominantly temperatures, dew point, pressures, and positions needed for test or control functions. This system acquires the data, computes engineering units and coefficients, performs some limit checking and alarming, and makes the data available via high speed networks to the tunnel control and facility management processors. Trend and historical performance data are archived for later analysis. Data is also passed to the data acquisition control processor for synchronization with the test data and for real-time display.

**DATA ACQUISITION CONTROL PROCESSOR** - This system acquires test measurements from the test section or a cart bay area and the tunnel parameters processor. Data is acquired from the test section or cart area via a high speed fiber optics network from processors on the model cart. Test information from the test section is synchronized with the tunnel parameter information, reduced to engineering units and coefficients, and passed through high speed networks to other data processing, analysis, and control systems. This processor also provides real-time display to the data acquisition system operator's console. This processor handles the sequencing of all data acquisition related processes when commanded by the operator or by the facility management processor and when test conditions are achieved. This processor also alerts the facility management processor when data has been acquired so that test conditions can be set for the next test point.

**DATA PROCESSING WORKSTATIONS** - These workstations receive test data for the data acquisition processor via a high speed network. This data is then processed in near real-time for the test engineer's test console as well as other stations. Data will be represented through a high end graphical user interface that will present data in a flexible, easy format that can quickly be changed by the engineer.

**DATA ANALYSIS WORKSTATIONS** - These workstations will have high end graphics capability to provide near real-time quality graphics that can be readily compared with previous test conditions stored on the data archive file server. These displays will be located near the test engineer's console and can be networked to the data analysis rooms.

**DEVELOPMENT AND SIMULATION** - These processors are available to support development and operations functions without interfering with the daily operations of the tunnels. Functions that will be supported include data acquisition systems software development, controls systems software development, simulation, documentation support, hardware and software system checkout, test preparation, and software configuration control. One processor will be provided for DAS support, one for controls, and a small file server for documentation and administrative services. These computers will also be configured in such a fashion that they can serve as backup processors for other processors on the control room network.

**DATA ARCHIVE FILE SERVERS** - This processor will be the repository for test data as it is being acquired. Tunnel process control data will also be archived on a separate server for post test analysis. Previous test configuration data or theoretical predictions will reside on this archive system so that they may be called up for analysis or comparison with the current test. Files will be maintained in a secure environment to provide access only as required. Optical disk storage will be provided for archiving large volumes for static and dynamic data, and high speed printers will be provided.

### **DATA ANALYSIS ROOMS**

Two rooms will be provided adjacent to the main control room for use by visiting test personnel during preparation, testing, and limited post test analysis. Both areas will be networked to the cart areas, the test section, and the main control room; however, each data analysis room will be capable of isolation for secret tests so that only appropriate networks are active to support setup in a model preparation area or test section. Each analysis room will have a file server for data archiving and analysis as well as several workstations and X terminals to support real-time data display and analysis during setup, calibration, and checkout prior to tunnel entry. Video projection systems will also be provided for displaying real-time or video from the test section.

**COMMUNICATIONS** - Since the system architecture uses a tiered, distributed system approach, communications networks will play a key role during systems operations. It is anticipated that high speed fiber optics networks will be used extensively throughout the system. The proposed system will offer support for LAN/Ethernet 802.3, FDDI, IEEE 488, RS 232/422, reflective memory fiber optic systems, and other technologies appropriate at the time of construction.

### **CART INSTRUMENTATION SYSTEMS**

**TEST INSTRUMENTATION CART** - Each test cart contains a completely stand alone integrated data acquisition and control system. It is anticipated that the system will rely heavily on emerging VME, Futurebus, and VXI technology. A lower level control and data bus will be provided so that various systems on the cart will have access to the same transducer inputs for control functions as well as test measurements, where practical. Data will be patched from the model to a patch panel for easy model setup and checkout. A fiber optics network link will also be provided to the model for any on-board instrumentation. Signal conditioning will be provided by this data system or, in some cases, by ancillary equipment for unique instrumentation. A higher level local area network (LAN) fiber optics communications bus connects the various processors on the cart to allow exchange of processed information. The static DAS, the dynamic DAS, and model attitude control systems will remain as permanent systems on the cart, but additional systems to provide model engine simulator or high pressure air control, model surface control, probe control, or acoustic dynamic data acquisition can be installed as required. When these systems are added to the cart, they are connected to the data bus and inter-processor LAN communications bus which allows them to be integrated and controlled by software. Workstations and X terminals connect to the LAN to support the cart in the model build-up bay area. All calibration, model attitude, model engine simulator or high pressure air operation, model surface movement, hook-up and checkout can be accomplished with the data and control systems on the cart; however, a fiber optics network will connect the cart to either data analysis room for customer checkout before moving the cart to the tunnel. Power will be maintained on the cart during movement to the test section to maintain constant cooling to the analog equipment so as not to affect calibration coefficients or require a prolonged warm-up period.

**TEST STATIC DATA SYSTEM** - This system acquires data from the test model, the model support systems, and other areas adjacent to the test section. Full software support is included for signal conditioning, system calibration, system diagnostics, conversion of data to engineering units and coefficients, and driving of real-time display systems for the technicians during model set-up and calibration. Appropriate data is also passed to the on-cart model attitude control system for command and control of the model attitude, model engine simulators, and model surfaces. This system also synchronizes and controls the electronic

pressure scanning system for acquiring up to 2000 ports of pressure data. Up to 256 channels of analog data will be acquired and 24 channels of digital information. Digital information will include binary, BCD, Datex code, resolver inputs, and special instruments requiring RS 232 or IEEE 488 protocol. When the cart is moved to the test section, a single X terminal will be used to perform any required diagnostics through the data processor for final checkout. The cart will then be connected by a fiber optics LAN to the central control room where command and control will be conducted during the test.

**DYNAMIC PRESSURE DATA SYSTEM** - The dynamic pressure data system will acquire data from up to 80 channels of dynamic pressure instrumentation. It is anticipated that this system will have an analog to digital converter per channel with up to 10 megabytes of buffer ram per channel. Data will be dumped to high speed 20 Gigabyte removable disks for archiving. The control processor will support a graphical signal analysis package with the cart and will be controlled from the central control room during tunnel testing. Each channel will have programmable gain and filter setting with appropriate signal conditioning for the transducers. The system will acquire data at up to 100 KHz per channel.

**HOT WIRE ANEMOMETRY DATA SYSTEM** - This system will record data from special signal conditioners utilizing constant temperature and constant current controllers for hot wire and hot film sensors. In addition, 24 channel of microphone data will also be provided. This system is used to measure hot wire and hot film anemometry instrumentation mounted directly on the model or in the tunnel air flow areas. One complete system will be provided for each cart for both the LSWT and the TSWT. The system is composed of the following components:

- Sensors
- Surface Mounted Hot Film Anemometer CTA System
- Hot wire/Film Probe Anemometer CTA/CCA System
- Signal Conditioner AC/DC Splitter
- Static DAS (for reading DC component)
- Transient Data Recorder(TDR) DAS 100 KHz
- Transient Data Recorder(TDR) DAS 1.25 MHz
- Anemometer DAS CPU
- Anemometer DAS Workstation

**Sensors** - Two types of sensors are used, the constant temperature anemometer(CTA) and the constant current anemometer(CCA) hot wire probes and hot film. In addition, 24 microphones will be employed to acquire acoustic data at rates up to 100 KHz.

**Surface Mounted Hot Film Anemometer CTA System** - The sensing units are powered and signal conditioned by a multi-channel anemometer system which provides computer control of calibration, gain, offset, and filtering.

The output signal bandwidth is DC to 40 KHz and the output amplitude is 5 to 15 VDC and 1 to 750 millivolts AC.

**Signal Conditioner AC/DC Splitter** - The analog output signals from the anemometer system are input to the signal conditioner units. These multi-channel units buffer the incoming signal to two outputs. One output is AC coupled and one output is DC coupled. The AC coupled output amplifier will block the DC signal component and provide selectable gain to drive the maximum of 10.24 volts into the TDR. The DC coupled output amplifier will provide both gain and attenuation settings to drive or limit the maximum signal of 10.24 volts into the Static DAS.

**Anemometer Static DAS** - The Static DAS system consists of 80 channels of voltage inputs from the signal conditioner AC/DC splitter units. The Static DAS has programmable low pass filter and auto-ranging gain capability. The selectable filters will filter out the AC component of the anemometer signal. The channels, gains, and filter selection will all be contained in a scan table that resides in the DAS unit. The scan rate will also be programmable. The unit will provide self calibration and correction capability.

**Transient Data Recorder (TDR) DAS 100 KHz** - The TDR provides high speed sampling and recording of multiple analog inputs at data rates up to 250 KHz. Sampled data are stored in 10 MB of on-board DRAM for each analog channel. The data is off loaded between runs through a high speed data bus and to disk. The unit features a 16 bit analog to digital converter with input gain and low pass filtering. Unit calibration is accomplished using an external voltage calibration standard. Software and hardware features support system calibration. Several methods of triggering will be available, including program control, external logic signal, and analog level detection on one channel. Twenty four additional channels will be provided to acquire microphone data.

**Transient Data Recorder(TDR) DAS 1.25 MHz** - The TDR provides high speed sampling and recording of multiple analog inputs at data rates up to 1.25 MHz. Sampled data are stored in 10 MB of on-board DRAM for each analog channel. The data is off loaded between runs through a high speed data bus and to disk. The unit features a 16 bit analog to digital converter with input gain and low pass filtering control. Unit calibration is accomplished using an external voltage calibration standard. Software and hardware features support system calibration. Several methods of triggering will be available, including program control, external logic signal, and analog level detection on one channel.

**Anemometer DAS CPU** - The Anemometer DAS CPU will act as the host for

controlling the data acquisition with the Anemometer Static DAS, the TDR 100 KHz and the TDR 1.25 MHz. The calibration calculations and engineering units conversion will also take place in the DAS CPU. The DAS CPU will put the converted data out on the local area network as well as storing it on a local hard disk. A graphical user interface package will be provided to control the acquisition process.

**Anemometer DAS Workstation** - The DAS workstation will act as the operator interface for the entire anemometer system. The local area network will provide the link between the anemometer DAS CPU and the workstation. The programming and scan list creation, scan initialization, synchronization and semi-real time graphical display of the resultant data will all be functions of the workstation. Software to run FFT's and perform other signal analysis on the data will also be available. The operator interface software will be a standard Windows compatible off the shelf package with enhancements.

**ACOUSTIC RAKE SURVEY DATA SYSTEM** - One high speed dynamic acoustic data system will be provided for the LSWT with an identical system being provided for the TSWT. The system will acquire data from up to 256 channels, 16 of which will be microphone data recorded up to 250 KHz per channel. the remaining 240 channels will be recorded at 50 KHz per channel. The system is anticipated to have a 16 bit analog to digital converter per channel with 10 million words of buffering per channel. Data will then be dumped to high speed disks. A data acquisition computer will be provided to allow signal analysis during set up and, from the control room, during testing. In addition, an acoustic survey wing will be controlled to acquire data during a survey of the noise field. An identical system will be provided for the TSWT.

## **7300 WIND TUNNEL BALANCES**

### **7310 LSWT Internal Strain-gage Balances**

Estimates for two high-range LSWT balances and two dummy balances were made for the following load range:

Lift	±81,000 lb.
Drag	±18,000 lb.
Side	±7,000 lb.
Pitching Moment	±41,000 ft-lb.
Rolling Moment	±37,000 ft-lb.
Yawing Moment	±19,000 ft-lb.

Estimates for the two low-range LSWT balances and dummy balances were made using the assumption that all LSWT balances would maintain the same physical

outline.

### **7320 TSWT Internal Strain-gage Balances**

Estimates for two high-range TSWT balances and two dummy balances were made for the following load range:

Lift	±54,000 lb.
Drag	±11,000 lb.
Side	±6,000 lb.
Pitching Moment	±42,000 ft-lb.
Rolling Moment	±19,000 ft-lb.
Yawing Moment	±7,000 ft-lb.

Estimates for the two low-range TSWT balances and dummy balances were made using the assumption that all TSWT balances would maintain the same physical outline.

### **7400 MODELS AND MODEL SUPPORTS**

#### **7410 Model Handling Equipment (LSWT)**

Equipment specified under this item is used within the various build-up bays to support and transport the model components until they are mounted to the sting, strut, etc. It is assumed that a crane system, used to remove the model from its shipping crates, is part of the build-up bay. The handling equipment consists of a cradle, mounted on wheels, with a range of lateral and fore and aft movement and a lifting mechanism, actuated mechanically or hydraulically. The cart will be used to place models into the individual test sections, and to remove the models from the test section after completion of the test(s). A cart will be required for each build-up area.

#### **7420 Model Handling Equipment (TSWT)**

Equipment specified under this item is used within the various build-up bays to support and transport the model components until they are mounted to the sting, strut, etc. It is assumed that a crane system, used to remove model components from shipping crates, is part of the build-up bay. The handling equipment consists of a cradle, mounted on wheels, with a range of lateral and fore and aft movement and a lifting mechanism, actuated mechanically or hydraulically. The cart will be used to place models into the individual test sections, and to remove the models from the test section after completion of the test(s). A cart will be required for each build-up area.

## 7430      Stings and Struts (LSWT)

The Low Speed Wind Tunnel will accommodate a variety of models and mounting options, including stings, struts, rod supports, and floor or wall semi-span model mounts. An assortment of stings, struts, and other mounting hardware items adequate for activation is to be provided in the initial acquisition. Each system will be designed to support full model loads with appropriate load ratings, with "infinite" fatigue life, based on applicable design criteria. Stings, struts, and model supports whose failure could endanger a model or the facility shall be fabricated from certified materials, inspected with non-destructive methods, and conform to locally established and/or national design practices and standards. A record of initial and subsequent inspections will be maintained at the facility, to allow for comparisons and the development of a history. Inspection intervals will be established based on conservative life cycle assumptions, and may be revised later on the basis of ongoing inspections. Model loads are defined as follows:

### Sting mounted Models

#### With no Roll and Full

#### Span Floor Mount

Normal Force	±81,000 lb.
Axial Force	±18,000 lb.
Side Force	±7,000 lb.
Pitch Moment	±41,000 ft-lb.
Roll Moment	±37,000 ft-lb.
Yaw Moment	±19,000 ft-lb.

(Referenced at the model 1/4 Mean Aerodynamic Chord)

### Full Span Models With Roll Capability

Normal Force	±56,000 lb.
Axial Force	±12,000 lb.
Side Force	±5,000 lb.
Pitch Moment	±24,000 ft-lb.
Roll Moment	±21,000 ft-lb.
Yaw Moment	±11,000 ft-lb.

(Referenced at the model 1/4 Mean Aerodynamic Chord)

### Half Models (External Balance)

Normal Force	±112,000 lb.
Axial Force	±24,000 lb.

Side Force	±18,000 lb.
Pitch Moment	±94,000 ft-lb.
Roll Moment	±840,000 ft-lb.
Yaw Moment	±118,000 ft-lb.

(Referenced at the model 1/4 Mean Aerodynamic Chord)

(These loads are provided in wind axis model coordinates, referenced to the center of the tunnel at the floor.)

- **Stings:** Two sting configurations will be specified initially. The stings will mount either to the pitch strut or to the pitch strut roll mechanism through a common joint. The distance from the model pitch point to the pitch strut is assumed to lie between 14 feet and 18 feet. Sting costs include a sub contract for through hole "gun drilling" and material certification and inspection. Two stings of each size will be provided to allow for model build-up activities while testing is underway for a total of four stings to be procured. Several adapters must be provided to accommodate known user furnished balances and to provide for model positioning in the test section. It is assumed that five adapters will be identified for initial acquisition, with one adapter specially designed to handle large mass flow rates of heated propulsion simulation air (100 lbm/sec at 3000 psi).
- **Struts:** Two floor mounted strut systems are required for external balance (Force Model) testing. The single strut design incorporates air lines for propulsion testing with Turbine Powered Simulators (TPS) or ejectors, and balance and/or sting mounting provisions. The air lines will be sized to handle heated propulsion air (100 lbm/sec at 3000 psi), and will have passages for multiplexed data cables, balance cables, model utilities, etc. The triple strut support system will have similar capability to the single strut, with activation of the aft strut to provide angle of attack capability, and will mount either to a solid floor insert or to a turntable. Both struts will be rated to full model loads with "infinite" fatigue life.
- **Semi-Span Model Mount:** The removable floor mount hardware includes the turntable plate, blanking plates, and the balance adapter assembly. Any other components required to provide a common mounting interface between the external balance and semi-span models will be included in this item.

#### **7440      Stings and Struts (TSWT)**

The Transonic Speed Wind Tunnel will accommodate a variety of models and mounting options, including stings, plate mounts, rod supports, and floor semi-

span model mounts. An assortment of stings, struts, and other mounting hardware items is to be provided in the initial acquisition. Each system will be designed to support full model loads with appropriate load ratings, with "infinite" fatigue life, based on applicable design criteria. Stings, struts, and model supports whose failure could endanger a model or the facility shall be fabricated from certified materials, inspected with non-destructive methods, and conform to locally established and/or national design practices and standards. A record of initial and subsequent inspections will be maintained at the facility, to allow for comparisons and the development of a history. Inspection intervals will be established based on conservative life cycle assumptions, and may be revised later on the basis of ongoing inspections. Model load ratings are as follows:

**Full Models (Internal Balance  
With no Roll Capability and  
External Balance)**

Normal Force	±54,000 lb.
Axial Force	±11,000 lb.
Side Force	±6,000 lb.
Pitch Moment	±42,000 ft-lb.
Roll Moment	±19,000 ft-lb.
Yaw Moment	±7,000 ft-lb.

(Referenced at the model 1/4 Mean Aerodynamic Chord)

**Full Models (Internal Balance  
With Roll Capability and  
External Balance)**

Normal Force	±27,000 lb.
Axial Force	±6,000 lb.
Side Force	±3,000 lb.
Pitch Moment	±15,000 ft-lb.
Roll Moment	±7,000 ft-lb.
Yaw Moment	±3,000 ft-lb.

(Referenced at the model 1/4 Mean Aerodynamic Chord)

**Half Models (Internal and  
External Balance)**

Normal Force	±54,000 lb.
Axial Force	±11,000 lb.
Side Force	±11,000 lb.
Pitch Moment	±59,000 ft-lb.
Roll Moment	±221,000 ft-lb.
Yaw Moment	±89,000 ft-lb.

(Referenced at the model 1/4 Mean Aerodynamic Chord)

(These loads are provided in wind axis model coordinates, referenced to the

center of the tunnel at the floor.)

- **Stings:** Two sting configurations will be specified initially. The stings will mount either to the pitch strut or to the pitch strut roll mechanism through a common joint. The distance from the model pitch point to the pitch strut is assumed to lie between 14 feet and 18 feet. Sting costs include a sub contract for through hole "gun drilling" and material certification and inspection. Two stings of each size will be provided to allow for model build-up activities while testing is underway for a total of four stings to be procured. Several adapters must be provided to accommodate known user furnished balances and to provide for model positioning in the test section. It is assumed that five adapters will be identified for initial acquisition, with one adapter specially designed to handle heated propulsion simulation air (100 lbm/sec at 3000 psi).
- **Struts:** Two floor mounted strut systems are required for external balance (Force Model) testing. The single strut design incorporates air lines for propulsion testing with Turbine Powered Simulators (TPS) and balance and/or sting mounting provisions. The air lines will be sized to handle full propulsion air delivery (100 lbm/sec at 3000 psi) and will have passages for multiplexed data cables, balance cables, model utilities, etc. The triple strut support system will have similar capability to the single strut, with activation of the aft strut to provide for angle of attack capability, and will mount either to a solid floor insert or to a turntable. Both struts will be rated to full model loads with "infinite" fatigue life.
- **Plate Mount/Semi-Span Model Mount:** The removable floor mount hardware includes the turntable plate, blanking plates, and the balance adapter assembly. Any other components required to provide a common mounting interface between the external balance and semi-span models will be included in this item.

## **7500 INSTRUMENTATION**

Instrumentation is divided into three categories: instrumentation required for test measurements, instrumentation required to monitor tunnel operations, and instrumentation required to "calibrate" the tunnels. The Instrument Research Division of LaRC has taken an in-depth look at all three categories, particularly test measurements instrumentation, and made estimates along these discipline lines:

- Acoustics
- Anemometry

- Angle of Attack
- Flow Visualization
- Humidity
- Mach Number
- Model Deformation
- Position
- Pressure
- Skin Friction
- Temperature
- Vibration
- Video
- Windows

Estimates are also made for instrumentation system integration.

Optical access is extremely important to accommodate conventional and advanced measurement techniques that within 5 years can be applied in a production wind tunnel environment. These types of measurements can provide non-intrusive measurements of flow field and model parameters. Disciplines that require optical access include flow visualization, model deformation, and video systems. Also, some angle of attack and skin friction schemes require optical access. Windows are needed on all four sides of the test sections (carts).

#### **7510 Test Instrumentation, LSWT**

All test instrumentation will be an integral part of the test sections (carts). There will be four of these carts that are fully assembled and trolleyed to the tunnel. Each cart contains/provides the following "conventional" instrumentation:

- 24 channels of thermocouple cold junction compensation and measurement system for any type of thermocouple material.
- 3 channels of servo accelerometers (low frequency).
- 3 channels of skin friction measurement capability.
- 12 channels of piezoelectric transducers; i.e., pressure, acceleration, etc.
- 36 channels of force balance.
- 3 channels of angle of attack (AOA) conventional accelerometer.
- 18 channels of model surface control via activators, stepper motors, etc.

- 3072 channels of ESP measurement capability.
- 3 channel resolver to track position of sting, wall and floor rotation/movement.
- 80 channels of hot wire/film anemometer measurements.
- 24 channels of condenser microphones for acoustic measurements.
- 80 channels of dynamic (high frequency) piezoresistive pressure transducer measurements.

The "conventional" part of the instrumentation system is illustrated in Figure 7510.a

The rest of the instrumentation requires optical access. Windows are needed on all 4 sides of the test sections (carts). Each cart contains/provides the following "optical" instrumentation:

- Active target tracker - Camera array will monitor up to 256 channels of model mounted targets (LEDS) and track their movement. Signals will be conditioned by PC for use in model deformation. Possible use as AOA package.
- Laser diode light sheet - Laser diodes will generate light sheet to be monitored by video camera system to provide flow visualization.
- Flow Visualization and Model Deformation - 6 video cameras will feed a PC with frame grabber to provide model motion or deformation. System also to be used with light sheet for flow visualization.
- Surveillance/high speed video - Cameras for general model observation and 2 for high speed video.

The "optical" part of the instrumentation system is illustrated in Figure 7510.b.

#### **7520 Test Instrumentation, TSWT**

Same as for LSWT (7510).

#### **7530 Calibration, LSWT**

Instrumentation systems identified in 7510 and 7570 will be used in tunnel

calibration. In addition, instrumentation will be furnished to be used exclusively for tunnel shakedown/calibration. This includes centerline static pressures (300) with 2 channels of vibration, rotary rake for total and static pressures (40), circuit static pressures (475), compressor pressures (50), wall pressures (10), boundary layer rakes (30), 120 channels of temperature data, and strain measurements on the tunnel structure.

#### **7540 Calibration, TSWT**

Instrumentation systems identified in 7520 and 7580 will be used in tunnel calibration. In addition instrumentation will be furnished to be used exclusively for tunnel shakedown/calibration. This includes centerline static pressures (300) with 2 channels of vibration, and rotary rake for total and static pressures (40), circuit static pressures (475), compressor pressures (50), wall pressures (10), boundary layer rakes (30), 120 channels of temperature data, and strain measurements on the tunnel structure.

#### **7550 Acoustics, LSWT**

The baseline requirement for acoustic measurements specifies eighteen, 0.5 inch microphones per test cart to be used with traversing model systems. Six additional 0.5 inch microphones have been added for test section acoustic measurements. The test acoustic measurements require a 20 KHz bandwidth and the tunnel calibration requires 40 KHz bandwidth according to the specification for the wind tunnel acoustic requirements. The systems will provide acoustic data over a 5 Hz to 40 KHz bandwidth, a dynamic range of 96 dB , and sound pressure levels up to 164 dB. The systems will provide acoustic data for tunnel baseline calibration, test acoustic data and measurements.

#### **7560 Acoustics, TSWT**

System described under 7550 will be shared with the TSWT.

#### **7570 Process Instrumentation, LSWT**

Process instrumentation capable of measuring pressure, force, acceleration, dewpoint, Mach Number, and temperature are located inside the pressure shell at strategic locations within the plenum.

- 48 channels of strain gage (bridge) type transducers capable measuring; acceleration., pressure, force, eddy currents, etc.
- 144 channels of cold junction compensation for any type of thermocouple material.

- 12 channels of piezoelectric transducers; ie pressure, acceleration, etc.
- 1024 channel of ESP measurement capability for pressure measurements.
- 3 channels/wall modified AoA without bubble for wall angle measurements.
- 2 independent Mach Number measuring systems.
- 4 channels of fast response dew point measurement capability (1 channel on model cart).

The "process" instrumentation system is illustrated in Figure 7570.a.

**Note: DOES NOT INCLUDE TUNNEL CONTROL OR SAFETY INSTRUMENTATION**

**7580 Process Instrumentation, TSWT**

Same as 7570 - PROCESS INSTRUMENTATION - LSWT.

**7590 Hardware Integration, LSWT**

The model cart wiring assumes a mobile cart scheme that consists of the test section floor and attached instrument house. The pressure feedthrus for all model instrumentation will penetrate the instrument house wall that will make up part of the pressure vessel when installed in the tunnel. Wires attached to instrumentation inside the model or sting will exit thru the test section floor and then exit the tunnel thru the instrument house pressure wall. It was universally agreed among the various optical systems consultants that a production oriented facility would require the complete test section (not just the floor) to be made available in the model prep bays for set-up, alignment, and equipment warm-up and stabilization. Concept A does not provide the opportunity to make optical measurements in a production environment and would require extensive modifications to the instrumentation if qualified below 10 °C. The concept presented in the optical systems wiring diagram would require permanent feedthrus mounted on one wall of the main test section plenum near the area that the model cart instrument house would reside. Optical instruments could then be patched into the instrument house after the cart assembly was in place and ready for a test run. The process instrumentation wiring has been designed to provide flexibility during normal testing and also provide tunnel calibration facilities when used in conjunction with one of the mobile model carts. One ESP system (two counting the cart system) will make up the majority of pressure measurements. The Mach Number System will include 2 complete independent measuring systems for redundancy. The three uniform temperature references (UTR) have the ability to provide cold junction compensation for any type of thermocouple and can also be used for any analog signal input to the data systems. The strain gage junction boxes will provide power, sense, R-Cal, and signal conditioning for discrete bridge type instrumentation. These junction boxes can also be used to input other analog signals into the data system.

**75AO Hardware Integration, TSWT**

Same as 7590 Hardware Integration, LSWT.

**75B0 Auxillary Process Instrumentation (LSWT&TSWT)**

This item contains instrumentation required for support of facility operations.

**7600 OPERATIONS INTEGRATION ANALYSIS PLAN**

These items moved to WBS 8350.

## **7700 CONTROLS**

### **7710 Controls - Auxiliary Process Systems**

Auxiliary systems common to both tunnels consist of high pressure air, cooling water, vacuum, and model cart staging/transport. High pressure air is used for tunnel pressurization and model propulsion simulation. The systems shall be designed with redundancy such that there are no single points of failure that will affect system operation or safety. Programmable Logic Controllers (PLC's) are used for the high pressure systems to provide interlocks, control of discrete devices, analog control loops, and a fiber digital data interface to the control room. Commands from the control room provide coordination and process set points. Model cart handling is a stand alone activity and provides limited automatic operation. Operator involvement is required for cart movement and transfer of model support systems into the tunnel plenum. Redundant sensors and PLC's are utilized for safety critical interlocks. Operator stations are provided throughout the model preparation area. PLC's are used for interlocks, control of discrete devices, and generation of operator displays.

### **7720 Controls - LSWT**

Integrated controls and test data acquisition systems are used in both tunnels. They provide automated execution of test sequences, automated start up and shut down of auxiliaries, and comprehensive tunnel process monitoring with diagnostics. The system shall be designed with redundancy such that there are no single points of failure that will affect safety or system operation. Sensors supplying test data and process data are shared where practical and pre-run calculations are utilized in addition to selective redundant sensors to maximize tunnel availability. Separate control rooms and control systems for each tunnel are specified to minimize down time and eliminate possible security issues. Operator interfaces consist of workstations (x-window terminals) with uniformity of displays and operational procedures between tunnels. Operators have three levels of control authority which consist of coordinated control of tunnel processes, control of set points to individual processes, and control of actuation devices.

A two tier architecture of computer hardware is used which stresses networking and distributed control. In addition, a high commonality of components in both the control and data acquisition systems is desired to minimize spares and maintenance difficulties. In the control room, UNIX (with real time extensions) based computers provide the acquisition of data, management of tunnel process data, control of tunnel processes, and interfaces to the operators. The lower tier of hardware consists of programmable logic controllers (PLC's) which provide a uniform interface between the control room and tunnel processes. They provide

limit checking, interlocks, and closed loop control of the process variables for stand alone subsystem checkout. The lower tier also utilizes PLC's to provide overall tunnel interlocks and control of discrete devices. Redundant PLC's are required for safety critical interlocks. Start up and shut down of tunnel auxiliaries are controlled at this level. Networking between hardware elements is accomplished with fiber digital data interface (FDDI) components which provide a 100 mb/sec data path.

Figure 7720.a depicts the layout of tunnel control hardware. The Tunnel Parameter Data Acquisition System (DAS) acquires tunnel status from various sensors throughout the tunnel, processes the data, and passes it to other systems via the network. The Facility Management System logs tunnel data for historical purposes, generate real time displays to operators, and provides trending and other analyses of data for tunnel health and maintenance purposes. The Tunnel Controls system provides automatic execution of tests including bringing the tunnel up to an operating point, conducting the predefined test sequence, and de-energizing the various tunnel process subsystems. To eliminate traditional problems with conflicting data from multiple sensors (test and process) and multiple acquisitions of data from the same sensor, data acquired by the Tunnel Parameter DAS are used by the Tunnel Controls System to control tunnel processes. Closed loop control is accomplished when communications to the subsystem controllers are provided by the Tunnel Controls System in the form of actuation device commands. To ensure safe operation, subsystem controllers monitor the same process sensors and disallow commands which may be inappropriate. Network activity is also monitored and loss of communication from the Tunnels Control System will initiate a safe subsystem controller takeover of the process. Start up and shut down of tunnel auxiliaries and subsystems are accomplished by commands from the Tunnel Controls system to the PLC's which control discrete devices throughout the complex.

Figure 7720.b shows the layout of equipment on the model support carts. Controls for model attitude, model control surfaces, and model engine simulation as well as optional controls for pressure and acoustic probes are contained on the cart and are capable of operation while in a cart room. Local workstations are provided for operator interface to the various model related control systems. Model attitude and engine control are implemented with UNIX (with real time extensions) based computers and PLC's. Compensation for sting and balance bending is provided as well as provisions for alpha and beta sweeps. Test data acquired by the static data system is available via the network to the model control systems to accomplish these higher level functions. When the cart is placed in the tunnel, a fiber link to the control room permits the Tunnel Control System to have authority over cart operations.

**7730 Controls - TSWT**

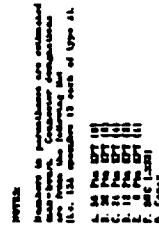
Integrated controls and test data acquisition systems are used in both tunnels. They provide automated execution of test sequences, automated start up and shut down of auxiliaries, and comprehensive tunnel process monitoring with diagnostics. The system shall be designed with redundancy such that there are no single points of failure that will affect safety or system operation. Sensors supplying test data and process data are shared where practical and pre-run calculations are utilized in addition to selective redundant sensors to maximize tunnel availability. Separate control rooms and control systems for each tunnel are specified to minimize down time and eliminate possible security issues. Operator interfaces consist of workstations (x-window terminals) with uniformity of displays and operational procedures between tunnels. Operators have three levels of control authority which consist of coordinated control of tunnel processes, control of set points to individual processes, and control of actuation devices.

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**Figure 7510.a NWTC Conceptual Design Model Cart Wiring Diagram**

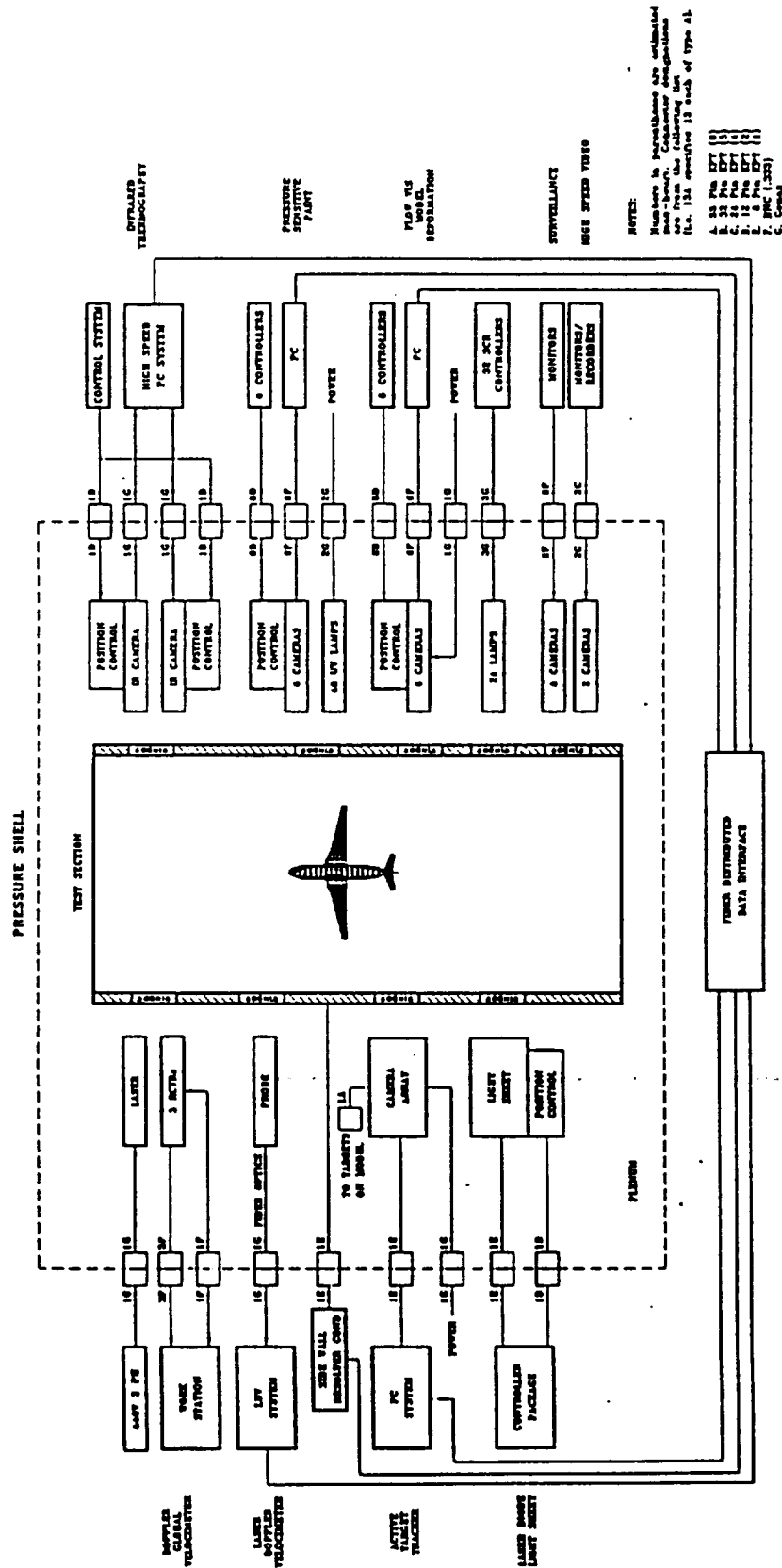
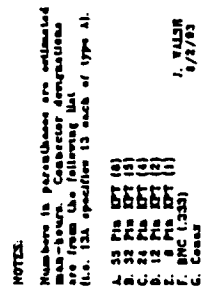


Figure 7510.b NWTC Conceptual Design Test Section Optical Systems Wiring Diagram



**Figure 7570.a NWTC Conceptual Design**

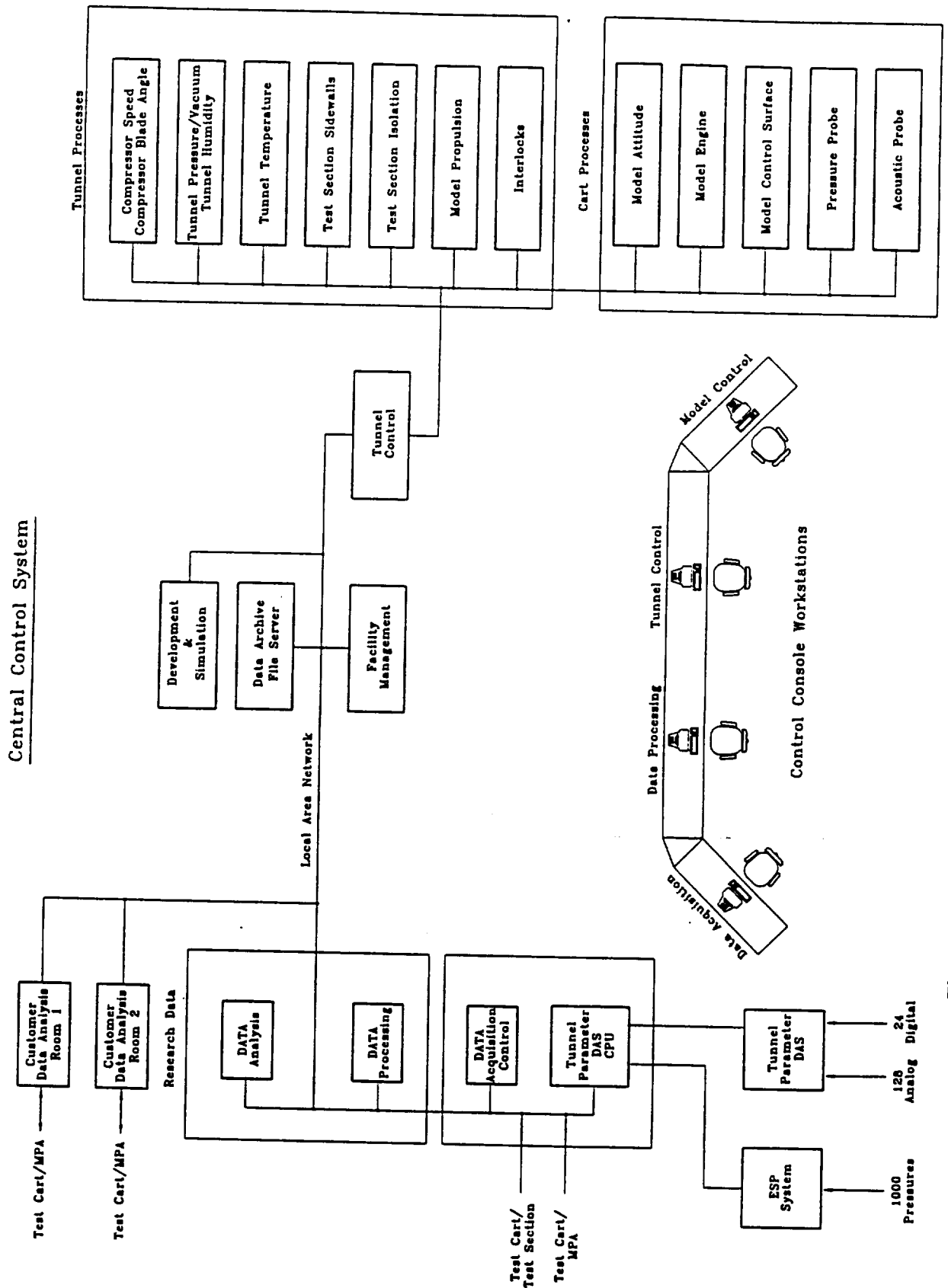


Figure 7720.a NWTC Central Control System Block Diagram

# Test Cart Instrumentation System

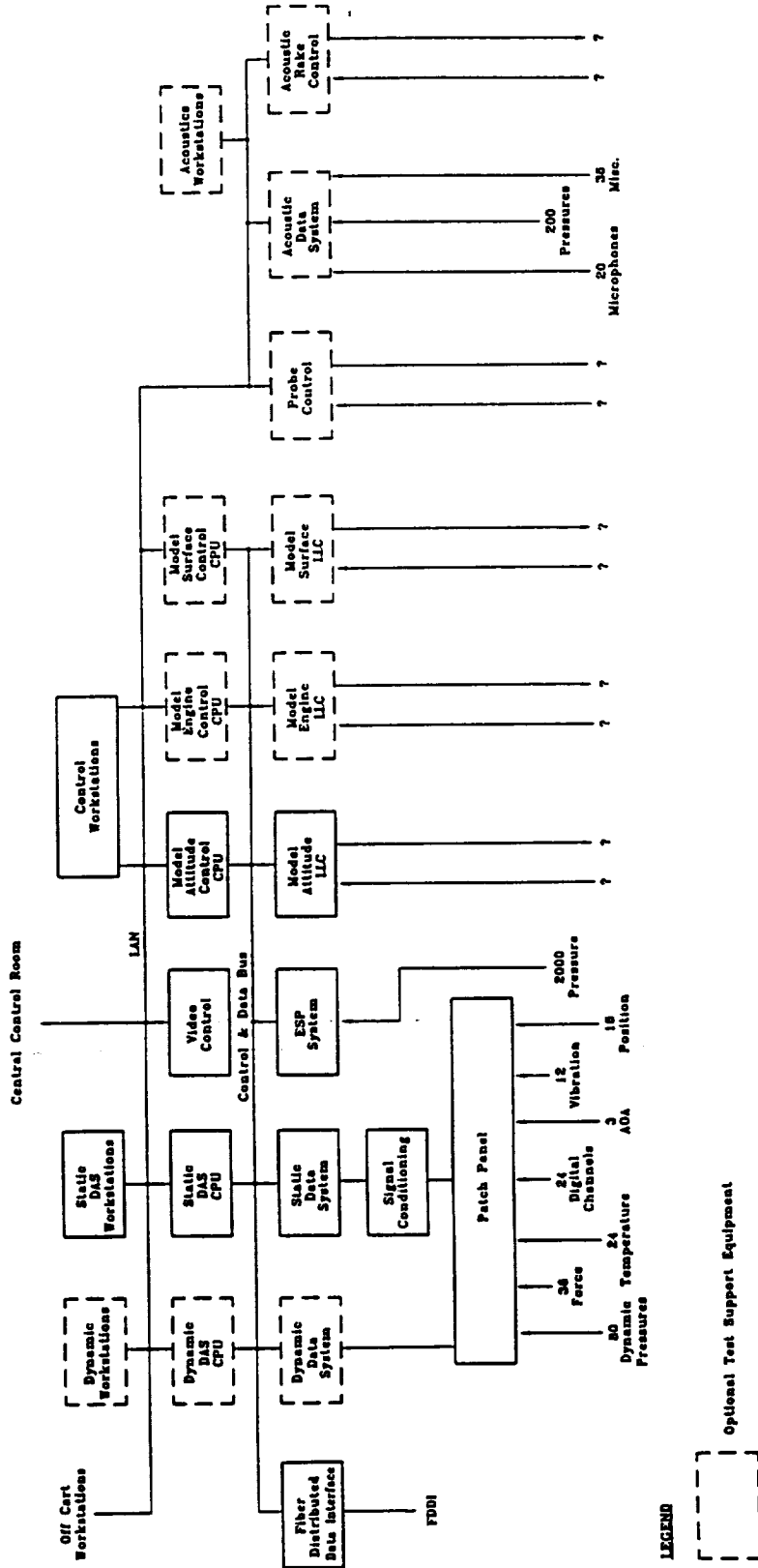


Figure 7720.b NWTC Test Cart Instrumentation Block Diagram

**ATTACHMENT 2.3**

**NATIONAL WIND TUNNEL COMPLEX**

**COST BASELINE CAPITAL COST ESTIMATE**



## **NATIONAL WIND TUNNEL COMPLEX**

### **Cost Baseline - Cost Estimate Summary**

The cost estimates developed are the program costs for the project. The costs include all elements necessary to provide a fully functioning complex. The cost estimates were developed based on the assumption of multi-tiering of contracts. The basic cost estimating assumptions used were:

1. The cost estimates were based upon a single prime contractor for the construction.
2. The Prime construction contractor would subcontract all elements of work. The cost estimates were developed based upon the idea that the actual element cost occurred at either the third or fourth tier. The costs developed are for a subcontractor to perform the work. The subcontractor costs include the price to perform the work including labor, materials, rentals, transportation, and shipping, overhead, general and administrative expenses, taxes, and profit.
3. The prime contractor costs to procure the work elements and to manage and administer the overall construction activities were included in WBS 8000. The prime contractor costs for labor, materials, offices, travel, overhead, general and administrative expenses, and taxes were included.
4. A cost risk, expressed as a percentage of the engineering estimate was assigned to each WBS work element to reflect the confidence level in the estimate. The construction cost estimate then was the engineering cost plus the risk factor. Risk factors considered were:
  - The maturity of the design (schematic or pre-design, sketch refinement and basic parameters, preliminary drawings and specifications, or working drawings and specifications).
  - Cost risk parameters such as certainty of requirements and site conditions
  - Complexity of the project such as the type of design (fixed principle design, adaptive design, or original design)
5. The design costs to produce the design and integrate the design into a system - were estimated for each WBS. The design services estimated were for "build to print" for all items except for the design/build elements (drive systems and pressure shells). Performance specifications were assumed for those items that would be design/build contracts.
6. The following items were added to the produce the Total Construction Budget Estimate:
  - Profit of 10% of the WBS subtotal (2nd Tier) for the Prime Contractor
  - Bond of 1% for the Prime Contractor
  - Cost adjustment for inflation to the mid-point of construction (7 years from the July 1, 1993 estimate date) at 3.5% per year. The 3.5% was based on the Army Corps of Engineers recommendations.
  - Project Contingency of 10%
  - Supervision, Inspection, and Engineering Services (SIES) at 8%.
7. Additional costs for the PER, studies, final design, and Government Project Management were included to provide the final Program Budget.

# Facilities Study Office

## Risk Assessment Considerations

### Complexity

Type of Design  
New Technology  
Developmental Systems  
New Materials  
Specialization

### Certainty

Requirements  
Site Conditions

### Design Maturity

Schematic - Pre-Design  
Sketch  
Preliminary Design  
Contract Drawings

# NATIONAL WIND TUNNEL COMPLEX

## PROJECT COST ESTIMATE (Dollars in Thousands)

### CONCEPT D - OPTION 5

<u>WBS</u>	<u>DESCRIPTION</u>	<u>Estimate</u>
1000	Site And Infrastructure	\$59,678
2000	Buildings	\$103,058
3000	Auxiliary Process System	\$148,947
4000	Low Speed Wind Tunnel	\$408,948
5000	Transonic Speed Wind Tunnel	\$352,514
7000	Operations (LSWT & TSWT)	\$106,479
8000	Management And Support	\$198,671
	<b>Engineering Estimate</b>	<b>\$1,378,295</b>
	Risk	<u>\$333,689</u>
	<b>Subtotal</b>	<b>\$1,711,984</b>
	Profit (10%)	\$171,198
	Bond (1%)	\$18,832
	Escalation (7 yrs. at 3.5%)	\$513,544
	Contingency (10%)	\$241,556
	SIES(8%)	<u>\$212,569</u>
	<b>Total Construction Budget</b>	<b>\$2,869,683</b>
	PER	\$46,000
	Government PM	\$151,005
	Studies	\$38,523
	Design	<u>\$118,181</u>
	<b>PROJECT TOTAL</b>	<b>\$3,223,393</b>

NATIONAL WIND TUNNEL COMPLEX										
Concept D - Option 5										
Project Cost Estimate										
(Dollars in Thousand)										
Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total	
1 1000 Site And Infrastructure			\$59,678	15%	\$68,808	\$4,050	\$72,857	\$72,857	\$72,857	
	1100	Site Preparation	\$0	0%	\$0	\$0	\$0	\$0		
	1110	Investigation (Design Process Only)	\$46	50%	\$69	5%	\$72			
	1120	Clearing And Grubbing	\$0	0%	\$0	\$0	\$0			
	1130	Demolition	\$0	0%	\$0	\$0	\$0			
	1140	Dewatering						\$5,619		
	1200	Site Improvements	\$1,856	15%	\$2,134	3%	\$2,198			
	1210	Earthwork	\$370	25%	\$463	3%	\$476			
	1220	Drainage	\$1,551	20%	\$1,861	6%	\$1,973			
	1230	Roads & Paving	\$0	0%	\$0	0%	\$0			
	1240	Rail System	\$376	15%	\$432	6%	\$458			
	1250	Waterway Improvements	\$52	10%	\$57	6%	\$61			
	1260	Landscaping	\$371	15%	\$427	6%	\$452			
	1270	Fencing And Gates						\$3,783		
	2 1300	Utility Supply and Distribution Systems								
	1310	Central Heat Pump System	\$0	0%	\$0	0%	\$0			
	1320	Central HVAC Chiller System	\$767	15%	\$882	6%	\$935			
	1330	Water Supply And Treatment System	\$256	15%	\$294	6%	\$312			
	1340	Sanitary Wastewater Collection And Treatment S	\$675	15%	\$776	6%	\$823			
	1350	Natural Gas Distribution System	\$937	15%	\$1,078	6%	\$1,142			
	1360	Yard Fire Protection System	\$468	15%	\$538	6%	\$570			
	1370	Compressed Air System	\$0	0%	\$0	0%	\$0			
	1380	Steam System						\$62,115		
	2 1400	Yard Electrical System	\$50,956	15%	\$58,599	6%	\$62,115			
	1410	Electrical Equipment	\$0	0%	\$0	0%	\$0			
	1420	Electrical Material (Included in 4110)								
	2 1500	Other Electrical Systems						\$1,268		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
				%		%			
	1510	Lighting Systems	\$71	20%	\$85	6%	\$90		
	1520	Communication Systems	\$209	20%	\$251	6%	\$266		
	1530	Security Systems	\$369	20%	\$443	6%	\$469		
	1540	Grounding	\$29	20%	\$35	6%	\$37		
	1550	Catholic Protection	\$101	20%	\$121	6%	\$128		
	1560	Lighting Protection	\$101	20%	\$121	6%	\$128		
	1570	Freeze Protection	\$57	20%	\$68	6%	\$73		
	1580	Environmental Monitoring	\$24	20%	\$29	6%	\$31		
	1590	DC Power for Instrumentation	\$36	20%	\$43	6%	\$46		
1	2000	Buildings	\$103,058	24%	\$127,963	\$7,604	\$135,567		\$135,567
1	2100	Test Preparations/Control Building						\$69,504	
	2110	LSWT/...Prep/Control	\$33,767	25%	\$42,209	6%	\$44,741		
	2120	TSWT/...Prep/Control	\$18,689	25%	\$23,361	6%	\$24,763		
1	2200	Wind Tunnel Drive Buildings						\$8,692	
	2210	LSWT/TSWT Drive Building	\$6,998	15%	\$8,048	8%	\$8,692		
	2220	Not Used	\$0	0%	\$0	0%	\$0		
1	2300	Support Buildings						\$39,160	
	2310	Model Shop And Warehouse	\$19,557	25%	\$24,446	6%	\$25,913		
	2320	Support Shop Building(Included in 2110)	\$0	0%	\$0	0%	\$0		
	2330	Engineering Office	\$2,051	20%	\$2,461	8%	\$2,658		
1	2340	Guard House	\$205	10%	\$226	6%	\$239		
	2350	Outfitting	\$8,625	20%	\$10,350	0%	\$10,350		
1	2400	Utility Buildings						\$18,211	
	2410	WT Press/Vac Building	\$5,077	25%	\$6,346	8%	\$6,854		
	2420	Not Used	\$0	0%	\$0	0%	\$0		
	2430	Heat Pump System Equipment Building	\$0	0%	\$0	0%	\$0		
	2440	HVAC Chiller Building	\$0	0%	\$0	0%	\$0		
	2450	Utility Tunnels	\$7,881	30%	\$10,245	8%	\$11,065		
	2460	Other Minor Buildings	\$208	30%	\$270	8%	\$292		
	2470	Motor Pool Vehicles (Transferred to 2350)	\$0	0%	\$0	0%	\$0		
3	3000	Auxiliary Process Systems	\$148,947	24%	\$184,325	\$10,348	\$194,673		\$194,673
3	3100	Test Model And Cart Transport						\$6,698	
	3110	LSWT Shuttle Cart	\$2,600	30%	\$3,380	12%	\$3,786		
	3120	TSWT Shuttle Cart	\$2,000	30%	\$2,600	12%	\$2,912		
3	3200	Wind Tunnel Pressurization/Vacuum System						\$110,040	
	3210	Compressors, Driers, Pumps, Etc.	\$43,394	30%	\$56,412	3%	\$58,105		
	3220	Heaters And Coolers	\$915	20%	\$1,098	10%	\$1,208		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	3230	Drier System	\$8,753	20%	\$10,504	1%	\$10,509		
	3240	Filters	\$1,378	20%	\$1,655	1%	\$1,671		
	3250	Distribution Piping	\$14,474	20%	\$17,369	10%	\$19,106		
	3260	Storage Tanks	\$12,360	15%	\$14,214	6%	\$15,067		
	3270	Muffler Towers	\$1,384	15%	\$1,603	6%	\$1,699		
	3280	Vacuum System	\$2,209	10%	\$2,430	6%	\$2,576		
	3							\$20,218	
	3400	Cooling System							
	3410	Cooling Towers	\$8,652	20%	\$10,382	2%	\$10,590		
	3420	Cw Circ Pumps & Motors	\$3,254	25%	\$4,068	2%	\$4,149		
	3430	Miscellaneous Equipment	\$138	25%	\$173	8%	\$186		
	3440	Distribution System Piping	\$4,084	20%	\$4,901	8%	\$5,293		
	6	Not Used							
	3							\$42,089	
	3600	Miscellaneous Support Systems							
	3610	Tunnel Cleaning System	\$3,600	30%	\$4,680	10%	\$5,148		
	3620	Calibration System (High Pressure Air/Model Pro	\$26,866	25%	\$33,583	10%	\$36,941		
	3630	Compressor Blade Handling System(Transferred	\$0	0%	\$0	0%	\$0		\$0
	3								
	3700	Scavenging And Fire Suppression System							
	3710	Combustible Gas Scavenging System (Not used)	\$0	0%	\$0	0%	\$0		
	3720	Tunnel Fire Suppression System (Not used)	\$0	0%	\$0	0%	\$0		
	2							\$4,262	
	3800	Aux. Electrl Control Systems And Data Acquisition							
	3810	Electrical Equipment	\$3,496	15%	\$4,020	6%	\$4,262		
	3820	Electrical Bulks(Included in 3810)	\$0	0%	\$0	0%	\$0		
	3830	Control System (Transferred to 7710)	\$0	0%	\$0	0%	\$0		
	3840	Data Acquisition And Processing Systems (Trans	\$0	0%	\$0	0%	\$0		
	3							\$6,293	
	3900	Auxiliary Test And Validation							
	3910	Test And Validation	\$3,461	20%	\$4,154	1%	\$4,195		
	3920	Calibration	\$1,731	20%	\$2,077	1%	\$2,098		
	3A00	Productivity Provisions							
	3A10	Productivity Provisions	\$4,187	20%	\$5,024	1%	\$5,075		
	4		\$408,948	32%	\$537,867	\$33,075	\$570,942		\$570,942
	4	4000 Low Speed Wind Tunnel						\$34,939	
	4								
	4100	LSWT Enclosure							
	4110	Foundation	\$10,235	20%	\$12,282	8%	\$13,265		
	4120	Enclosure	\$15,317	20%	\$18,380	8%	\$19,851		
	4130	Acoustic Insulation	\$399	20%	\$479	6%	\$508		
	4140	Electrical Services	\$544	15%	\$626	6%	\$653		
	4150	Mechanical Services	\$536	15%	\$616	6%	\$653		
	4							\$198,433	
	4	LSWT Pressure Shell							

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	4210	LSWT Support Foundation( Incl. in 4110)	\$0	0%	\$0	0%	\$0		
	4220	LSWT Support Structure	\$16,400	25%	\$20,500	3%	\$21,115		
	4230	LSWT Pressure Shell	\$139,073	25%	\$173,841	2%	\$177,318		
4	4300	LSWT Pressure Isolation System						\$13,833	
	4310	LSWT Isolation Valves	\$7,380	60%	\$11,808	15%	\$13,579		
	4320	LSWT Personnel Access (Not used)	\$0	0%	\$0	0%	\$0		
	4330	Hydraulic Power Unit	\$186	30%	\$242	5%	\$254		
	4340	Exhaust Silencer (Transferred to 3270)	\$0	0%	\$0	0%	\$0		
4	4400	LSWT Flow Internals						\$64,763	
	4410	Turning Vanes	\$9,861	30%	\$12,819	10%	\$14,101		
	4420	Honeycomb	\$3,347	40%	\$4,686	10%	\$5,154		
	4430	Screens	\$3,116	40%	\$4,362	10%	\$4,799		
	4440	Internal Heat Exchanger	\$9,685	20%	\$11,622	5%	\$12,203		
	4450	Settling Chamber Liner	\$15,687	30%	\$20,393	10%	\$22,432		
	4460	Plenum Evacuation System (Not used)	\$0	0%	\$0	0%	\$0		
	4470	Gas Manifolding(Not used)	\$0	0%	\$0	0%	\$0		
	4480	High Speed Diffuser	\$2,220	30%	\$2,886	10%	\$3,175		
	4490	Acoustic Treatment for nacelles	\$2,027	30%	\$2,635	10%	\$2,899		
	44A0	Compressor FOD Protection (Not Used)	\$0	0%	\$0	0%	\$0		
	44B0	Acoustic Baffles (Not used)	\$0	0%	\$0	0%	\$0		
	44C0	Tunnel Cleaning System(Transferred to 3610)	\$0	0%	\$0	0%	\$0		
4	4500	Test Plenum						\$120,555	
	4510	Subsonic Nozzle(Transferred to 4450)	\$0	0%	\$0	0%	\$0		
	4520	Flutter Test Section (Not in Concept )	\$0	0%	\$0	0%	\$0		
	4530	Open Jet Test Section	\$9,306	50%	\$13,959	15%	\$16,053		
	4540	Moveable Plenum	\$11,841	40%	\$16,577	10%	\$18,235		
	4550	Not used	\$0	0%	\$0	0%	\$0		
	4560	Observation System	\$385	40%	\$539	10%	\$593		
	4570	Test Section Carls	\$40,677	60%	\$65,083	15%	\$74,846		
	4580	Preparation Hall Shuttle Cart	\$0	0%	\$0	0%	\$0		
	4590	Anechoic Chamber	\$7,572	30%	\$9,844	10%	\$10,828		
4	4600	Test Support Equipment						\$21,839	
	4610	Vertical Strut Assembly (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
	4620	Floor Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
	4630	Half Model Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
	4640	Moving Ground Plane (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
	4650	Elevated Ground Plane	\$1,788	50%	\$2,682	10%	\$2,950		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	4660	Inverted Ground Plane	\$1,788	50%	\$2,682	10%	\$2,950		
	4670	Slings (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
	4680	External Balance	\$9,900	40%	\$13,860	15%	\$15,939		
								\$55,790	
6	4700	Compressor and Drive System							
	4710	Rotor Hub/Blades	\$9,750	30%	\$12,675	3%	\$13,055		
	4720	Shaft/Bearings/Clutch	\$2,960	25%	\$3,700	2%	\$3,774		
	4730	Nacelles/Fairings and Supports	\$2,200	30%	\$2,860	5%	\$3,003		
	4740	Gearbox	\$0	0%	\$0	0%	\$0		
	4750	Lubrication and Cooling System	\$200	20%	\$240	5%	\$252		
	4760	Motor	\$4,500	20%	\$5,400	1%	\$5,454		
	4770	Motor Drive Controls	\$13,500	20%	\$16,200	2%	\$16,524		
	4780	Compressor Pressure Shell/Stators/IGV/OGV	\$8,800	50%	\$13,200	4%	\$13,728		\$0
6	4800	Electrical, Controls System and Data Acquisition							
	4810	Electrical Equipment (Transferred to 1410)	\$0	0%	\$0	0%	\$0		
	4820	Electrical Materials (Transferred to 1420)	\$0	0%	\$0	0%	\$0		
	4830	Control and Instrumentation (Transferred to 7720)							
	4840	Data Acquisition and Processing Systems (Transferred to 7220)						\$40,526	
4	4900	Test & Validation							
	4910	Test and Validation	\$23,884	20%	\$28,661	1%	\$28,947		
	4920	Calibration	\$9,554	20%	\$11,464	1%	\$11,579		
	4A00	Productivity Provisions						\$20,263	
	4A10	Productivity Provisions	\$14,330	40%	\$20,063	1%	\$20,263		
			\$352,514	30%	\$460,019	\$29,708	\$489,728		\$489,728
5	5000	Transonic Wind Tunnel (TSWT)						\$25,760	
5	5100	TSWT Enclosure							
	5110	Foundation	\$7,627	20%	\$9,152	8%	\$9,885		
	5120	Enclosure	\$11,400	20%	\$13,680	8%	\$14,774		
	5130	Acoustic Insulation	\$284	20%	\$341	6%	\$361		
	5140	Electrical Services	\$306	15%	\$352	6%	\$373		
	5150	Mechanical Services	\$301	15%	\$346	6%	\$367		
5	5200	Pressure Vessels						\$62,843	
	5210	Foundations	\$0	0%	\$0	0%	\$0		
	5220	Shell Support System	\$4,700	25%	\$5,875	5%	\$6,169		
	5230	TSWT Pressure Shell	\$43,180	25%	\$53,975	5%	\$56,674		
								\$9,431	
5	5300	Pressure Isolation System							
	5310	TSWT Isolation Valves	\$4,000	100%	\$8,000	15%	\$9,200		
	5320	TSWT Personnel Access	\$0	0%	\$0	0%	\$0		
	5330	Hydraulic Power Unit	\$150	40%	\$210	10%	\$231		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
5	5400	TSWT Flow Internals							
	5410	Turning Vanes	\$4,275	20%	\$5,130	10%	\$5,643		
	5420	Honeycomb	\$1,019	30%	\$1,325	10%	\$1,457		
	5430	Screens	\$1,400	30%	\$1,820	10%	\$2,002		
	5440	Internal Heat Exchanger	\$8,056	30%	\$10,473	10%	\$11,520		
	5450	Settling Chamber Liner	\$2,040	40%	\$2,856	10%	\$3,142		
	5460	Plenum Evacuation System	\$23,240	20%	\$27,888	5%	\$29,282		
	5470	Acoustic Baffles	\$600	20%	\$720	15%	\$828		
	5480	Flexible Nozzle	\$9,500	40%	\$13,300	15%	\$15,295		
	5490	Compressor FOD Protection	\$3,400	20%	\$4,080	15%	\$4,692		
	54A0	Choke System	\$3,100	30%	\$4,030	20%	\$4,836		
	54B0	High Speed Diffuser Liner	\$975	40%	\$1,365	15%	\$1,570		
	54C0	Ejection System	\$0	30%	\$0	12%	\$0		
5	5500	TSWT Test Plenum						\$104,846	
	5510	Test Section	\$60,500	40%	\$84,700	12%	\$94,864		
	5520	Moveable Plenum	\$6,000	40%	\$8,400	15%	\$9,660		
	5530	Observation System	\$200	40%	\$280	15%	\$322		
	5540	Preparation Hall Shuttle Cart	\$0	0%	\$0	0%	\$0		
5	5600	TSWT Test Support Equipment						\$7,084	
	5610	Model Support (incl. in 5510)	\$0	0%	\$0	0%	\$0		
	5620	Floor Mounts (interface only)	\$0	0%	\$0	0%	\$0		
	5630	Half Model Mounts(interface only)	\$0	0%	\$0	0%	\$0		
	5640	Slings and Booms(incl. in 7440)	\$0	0%	\$0	0%	\$0		
	5650	External Balance	\$4,400	40%	\$6,160	15%	\$7,084		
	5660	Other Test Support Equipment(incl. in 7740)	\$0	0%	\$0	0%	\$0		
6	5700	TSWT Compressor Drive System						\$151,196	
	5710	Rotor Hub/Blades	\$27,020	40%	\$37,828	2%	\$38,585		
	5720	Shaft/Bearings/Clutch	\$7,660	35%	\$10,341	2%	\$10,548		
	5730	Nacelles/Fairings and Supports	\$6,900	45%	\$10,005	5%	\$10,505		
	5740	Compressor Pressure Shell/Stators/IGV/OGV	\$12,660	45%	\$18,357	4%	\$19,091		
	5750	Lubrication & Cooling System	\$340	20%	\$408	5%	\$428		
	5760	Motors	\$14,750	20%	\$17,700	1%	\$17,877		
	5770	Motor Controls	\$44,250	20%	\$53,100	2%	\$54,162		
	5780	Gearbox Included With 3530	\$0	0%	\$0	0%	\$0		
6	5800	TSWT Elec. Control Systems and Data Acquisition						\$0	
	5810	Electrical Equipment	\$0	0%	\$0	0%	\$0		
	5820	Electrical Materials	\$0	0%	\$0	0%	\$0		



Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	7560	Acoustics (TSWT)		0%	\$0	0%	\$0		
	7570	Processes (LSWT)	\$1,917	20%	\$2,300	12%	\$2,576		
	7580	Process (TSWT)	\$2,332	20%	\$2,798	12%	\$3,134		
	7590	Hardware Integ. (LSWT)	\$622	15%	\$715	15%	\$823		
	75A0	Hardware Integ. (TSWT)	\$622	15%	\$715	15%	\$823		
	75B0	Aux. process Instr. LSWT & BWT	\$714	30%	\$928	20%	\$1,114		
7	7600	Operations Integration Analysis Plan (Incl. in 8350)						\$0	
	7610	Productivity (LSWT)	\$0	0%	\$0	0%	\$0		
	7620	Productivity (TSWT)	\$0	0%	\$0	0%	\$0		
	7630	Maintenance (LSWT)	\$0	0%	\$0	0%	\$0		
	7640	Maintenance (TSWT)	\$0	0%	\$0	0%	\$0		
	7650	Maintenance - Aux. Syst.	\$0	0%	\$0	0%	\$0		
	7660	Instr. Acc. Assessment LSWT & TSWT	\$0	0%	\$0	0%	\$0		
7	7700	Controls						\$23,325	
	7710	Controls - Auxiliary Process Systems (from 3830)	\$1,480	15%	\$1,702	20%	\$2,042		
	7720	Controls - LSWT (from 4830)	\$6,595	30%	\$8,574	20%	\$10,288		
	7730	Controls - TSWT (from 5830)	\$7,048	30%	\$9,162	20%	\$10,995		
		Subtotal	\$1,179,624	28%	\$1,510,054	\$101,931	\$1,611,985	\$1,611,985	\$1,611,985
8	8000	Management and Support	\$198,671	2%	\$201,930	\$0	\$201,930		\$201,930
8	8100	Program Management						\$133,501	
	8110	Prime Contractor's Program Office	\$74,750	0%	\$74,750	0%	\$74,750		
	8120	Operator Training	\$21,000	0%	\$21,000	0%	\$21,000		
	8130	Maintenance and Operation Support	\$37,751	0%	\$37,751	0%	\$37,751		
	8140	Not used	\$0	0%	\$0	0%	\$0		
8	8200	Quality Assurance						\$0	
	8210	Quality Assurance	\$0	0%	\$0	0%	\$0		
8	8300	Systems Engineering and Integration						\$0	
	8310	Systems Engineering and Intergration	\$0	0%	\$0	0%	\$0		
	8320	General Engineering	\$0	0%	\$0	0%	\$0		
	8330	Performance/System Specifications	\$0	0%	\$0	0%	\$0		
	8340	Construction	\$0	0%	\$0	0%	\$0		
8	8400	Procurement						\$0	
	8410	Procurement	\$0	0%	\$0	0%	\$0		
8	8500	Construction Management						\$0	
	8510	Not used	\$0	0%	\$0	0%	\$0		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	8520	Not used	\$0	0%	\$0	0%	\$0		
	8530	Not used	\$0	0%	\$0	0%	\$0		
	8540	Not used	\$0	0%	\$0	0%	\$0		
	8600	Site and Permits							
	8700	Field Indirect	\$65,170	5%	\$68,429	0%	\$68,429	\$68,429	
		<b>Total</b>	<b>\$1,378,295</b>	<b>24%</b>	<b>\$1,711,984</b>	<b>\$101,931</b>	<b>\$1,813,915</b>	<b>\$1,813,915</b>	<b>\$1,813,915</b>
		<b>Project Assessment</b>				<b>6%</b>			<b>\$1,511,409</b>
		Profit				10%	\$171,198	\$1,883,182	
		Bond				1%	\$18,832	\$1,902,014	
		Cost Adjustment (7 yr. @ 3.5%)				27%	\$513,544	\$2,415,558	
		Construction Cost Estimate						\$2,415,558	
		Contingency				10%	\$241,556	\$2,657,114	
		SIES				8%	\$212,569	\$2,869,683	
		Total Construction Budget Estimate						\$2,869,683	
		PER					\$46,000	\$2,915,683	
		Government Project Management				10%	\$151,005	\$3,066,688	
		Studies					\$38,523	\$3,105,211	
		Design(Including Design Management)					\$118,181	\$3,223,393	
		Real Estate					\$0	\$3,223,393	
		Other Burden Expense					\$0	\$3,223,393	
		<b>Project Total</b>					<b>\$3,223,393</b>		<b>\$3,223,393</b>

**ATTACHMENT 2.4**

**NATIONAL WIND TUNNEL COMPLEX**

**COST BASELINE**

**PROGRAMMATIC SCHEDULE**

**AND**

**ANNUAL FUNDING**

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# NATIONAL WIND TUNNEL COMPLEX Program Schedule (Fiscal Years)

ID	Name	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
1	Site Selection Period	Q4 1994	Q1 1995	Q2 1995	Q3 1995	Q4 1995	Q1 1996	Q2 1996	Q3 1996	Q4 1996	Q1 1997
2	STUDIES										
3	Acq. of A/E Indefinite Quantity Studies Contract	Q4 1994	Q1 1995	Q2 1995	Q3 1995	Q4 1995	Q1 1996	Q2 1996	Q3 1996	Q4 1996	Q1 1997
4	Studies Performance Period										
5	PER / PD										
6	Acquisition of PER / PD	Q4 1994	Q1 1995	Q2 1995	Q3 1995	Q4 1995	Q1 1996	Q2 1996	Q3 1996	Q4 1996	Q1 1997
7	Concept Evaluations										
8	Preliminary Engineering Report Period	Q4 1994	Q1 1995	Q2 1995	Q3 1995	Q4 1995	Q1 1996	Q2 1996	Q3 1996	Q4 1996	Q1 1997
9	Preliminary Design										
10	DESIGN										
11	Acquisition Of Final Design Contract	Q4 1994	Q1 1995	Q2 1995	Q3 1995	Q4 1995	Q1 1996	Q2 1996	Q3 1996	Q4 1996	Q1 1997
12	Detail Design										
13	GFE PROCUREMENT										
14	Acquisition Of GFE Contracts	Q4 1994	Q1 1995	Q2 1995	Q3 1995	Q4 1995	Q1 1996	Q2 1996	Q3 1996	Q4 1996	Q1 1997
15	Long Lead Mat'l Contracts Period										
16	Design										
17	Build Hardware										
18	CONSTRUCTION										
19	Acquisition of Construction Contract	Q4 1994	Q1 1995	Q2 1995	Q3 1995	Q4 1995	Q1 1996	Q2 1996	Q3 1996	Q4 1996	Q1 1997
20	Field Construction										
21	Construct LSWT										
22	Construct TSWT										
23	Construct Aux. Systems										
24	ACTIVATION										
25	Activate Aux. Systems										
26	Activate LSWT										
27	Activate TSWT										

## **NATIONAL WIND TUNNEL COMPLEX COST BASELINE FUNDING PROFILE**

The funding profile was generated based upon the capital cost estimate. The funding profile shown is for Obligation purposes and not for Costing. The funding profile was leveled to reflect the realities of fiscal funding as well as the realities of the contracting methodology.

The funding profile was developed using the following assumptions:

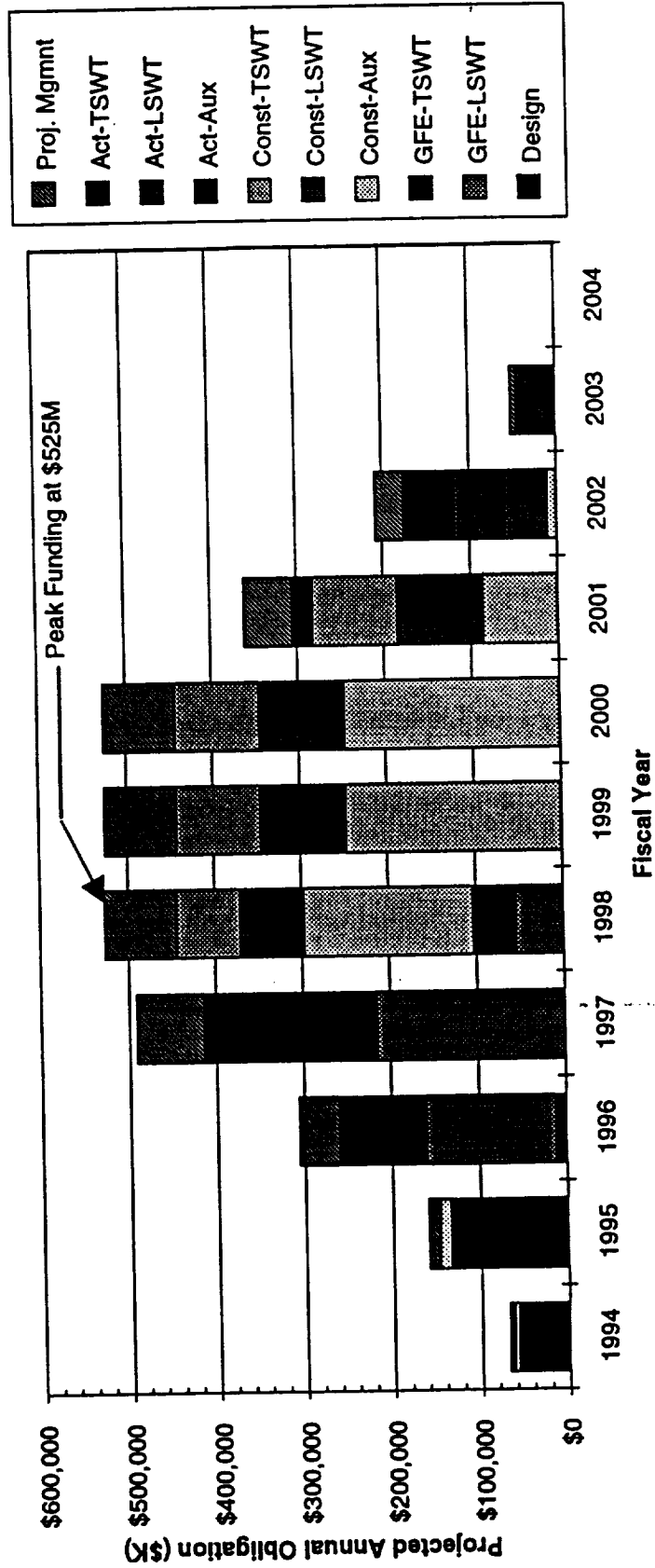
1. The WBS 8000 costs and Government Project Management costs are spread throughout based on the percent of the total project obligated that year.
2. The final year for funding studies is FY96. Study efforts would continue past that time with costing occurring in FY97.
3. All of the PER cost is applied to the contract at the time of contract award in FY94. (\$46M)
4. All of the final design cost is applied at the time of contract award in FY95. (\$118M)
5. The Engineering Building is the first structure erected at the site. This occurs early in the project final design so that the Government Project Office and the Design Contractors can be co-located during the design, construction, checkout, and calibration activities. It has been assumed that the Engineering Building would be a design and build contract to an A/E firm. It was assumed the entire cost of the Engineering Building occurred during FY94, (design and build contract for FFP with an A/E) (\$4M)
6. Assumed about \$1M of outfitting costs incurred during FY94 (ADP)
7. Assumed some of the site work occurred early (in FY95). All of WBS 1100, 1210, 1220, 1230 (\$1M out of 1.8M), 1240, 1250, 1260, 1270, and all of 1300 (except for 1370) (\$12M)
8. About 25% of the GFE would be funded during FY96, at time of award. This is for both tunnel pressure shells and both drive systems only.
9. About 45% of the GFE would be funded during FY 97, and the remaining 30% in FY98.
10. Program Duration is 9.5 Years.
11. Annual inflation rate is 3.5%. Constant rate over the life of the project.
12. Midpoint of construction is 7 years from the start of the project.

**Annual Obligation Table**

<b><u>Fiscal Year</u></b>	<b><u>Obligation (\$K)</u></b>
1994	\$68,180
1995	\$159,272
1996	\$306,348
1997	\$491,087
1998	\$526,712
1999	\$525,058
2000	\$525,058
2001	\$361,578
2002	\$207,769
2003	\$52,331
2004	\$0
<b>TOTAL</b>	<b>\$3,223,393</b>

# NATIONAL WIND TUNNEL COMPLEX

## Program - Baseline 10 Year Program Funding Profile



## **ATTACHMENT 2.5**

### **NATIONAL WIND TUNNEL COMPLEX**

#### **COST BASELINE**

#### **PRODUCTIVITY/OPERATING COST/LIFE CYCLE COST**



**COST BASELINE**  
**FACILITY STAFFING**



## STAFFING, SKILL MIX AND LABOR RATES

### General

This model for the staffing of the NWTC has been developed based on a generic facility site. This assumption necessitates that all necessary labor resources for the operation, maintenance and management of the complex be provided.

The staffing is based on a 3-shift-per-day, 5-day-per-week operating schedule in each tunnel. This equates to a total of 6 operating shifts-per-day, or 30 operating shifts per week. It is planned that maintenance activities will be performed both during operating shifts and during periods between tests. It is further assumed that an integration of responsibilities will allow work crews to perform both operations and maintenance activities, thereby reducing the inherent idle periods typical with separate crews. The facility is sufficiently staffed to allow concurrent operation of the LSWT and the TSWT.

Some planned major maintenance activities and significant facility improvement projects may be accomplished using outside contracts rather than the in-house workforce as dictated by workload.

A high degree of facility automation, centralized control, diagnostic features and operational flexibility is assumed. These features reduce the required staffing levels for the facility, particularly station-keeping type positions.

Specific skills types required for the facility were developed based on current practices at existing wind tunnel facilities with refinements to reflect technological and productivity improvements. Several areas of responsibility overlap between facility operator and facility customers were defined as follows:

1. The facility will provide the project engineering function for conduct of virtually all test functions. Customer personnel will typically provide test oversight, high level test direction and data analysis from their perspective, but they are not included in the staffing totals.
2. The facility will provide sufficient numbers of qualified model technicians for buildup and configuration change work under direction of the customer. Customers will likely use some of their own model technicians for certain tests, however these additional persons are not included in the staffing estimates.

### Staffing Model

The genesis of this model includes inputs from NASA/ARC, AEDC, and Boeing. Differences in the number and skill types between the ARC and AEDC inputs

were very small. The overall facility staffing by the Boeing model were significantly lower, primarily because the administrative functions were not included consistent with the generic site assumption.

The various inputs were integrated into an efficient organization for accomplishment of the facility test, support services, routine maintenance, and management activities. The resultant staffing model, for operations and maintenance, support, and administrative staff is presented in Tables 1, 2, and 3 respectively. The total proposed staffing for the facility is 200 permanent employees. A typical distribution of operations / maintenance personnel by workstation is provided in Table 4. It should be noted that the model buildup areas are planned for only two-shift coverage, while the tunnels are staffed for 3-shifts-per-day.

### **Labor Rates**

Labor rates for the generic site staffing analysis include all of the applicable overhead/fringe factors. These are assessed at a level of 60% of the basic hourly rate. Rates are in constant 1993 dollars. Escalation to the year of facility commissioning must be applied to the rates provided herein.

The composite labor rates and annual costs are presented in Tables 5, 6, and 7 for operations & maintenance, support, and administration respectively.

### **Summary**

Estimates for the staffing of the proposed NWTC, based on the assumed 3-shift-per-day operation will require a permanent staff of 200 people for the generically sited case. This model requires use of composite operations/maintenance crews and a streamlined management/administrative staff.

**Table 1: Operations and Maintenance Staff Requirements**

<b><u>SKILL</u></b>	<b><u>QUANTITY</u></b>
Project Engineers	18
Test Engineers	9
Instrument Engineers	6
Controls Engineers	3
Computer Scientists	7
Facility Engineers-Mechanical	4
Facility Engineers-Electrical	4
Facility Engineers-Computer/ADP	4
Craft Supervisors	4
Technical Assistants	7
Mechanics	26
Instrument Technicians	18
Electricians/Operators	22
Computer Operators	4
Laborers	3
<b>Total</b>	<b>139</b>

**Table 2: Test Support Staff Requirements**

<b><u>SKILL</u></b>	<b><u>QUANTITY</u></b>
Janitorial	5
Security	8
Machine Shop	6
Records	2
Communications	1
Library / Configuration Control	3
Photo	2
Safety / Environmental	1
Design / Drafting	6
QA / Calibrations	5
Clerical	8
<b>Total</b>	<b>47</b>

**Table 3: Administrative Staff Requirements**

<b><u>SKILL</u></b>	<b><u>QUANTITY</u></b>
General Manager	1
Supervisor	5
Personnel Office	2
Procurement	3
Business Office	3
<b>Total</b>	<b>14</b>

**December 13, 1993**

#### Table 4: Typical Operations and Maintenance Staff Distribution in Facility

PERSON	LOCATION/FUNCTION										TUNNEL AREA (NOT AT WORK)	VAC/SICK	TOTALS	
	OFFICE		BUILDUP		TESTING		TESTING		TUNNEL AREA (NOT AT WORK)					
	PLAN/ANAL	LSWT #1/#2	BUILDUP	LSWT #1/#2	TESTING	LSWT CONT. RM	TSWT CONT. RM	MAINT. AMP.						
PROJECT ENG.	4	1.0/1.0.0	1.0/1.0.0	1.0/1.0.0	1.0/1.0/1.0	1.0/1.0/1.0	1.0/1.0/1.0							15
TEST ENG.	1	0.5	0.5	1.0/1.0/1.0	1.0/1.0/1.0	1.0/1.0/1.0	1.0/1.0/1.0							8
INST. ENG.	2	0.5	0.5	0.5	0.5	0.5	0.5			1				5
CONTROLS ENG.			0.5	0.5						1				2
COMP. SCIENTIST	2	1	1	1	1	1	1							6
FACILITY ENG.	2	.25/.25.0	.25/.25.0	.25/.25/5	.25/25/5	.25/25/5	.25/25/5			3				8
												6		6
											Subtotal			50
CRAFT SUPV.		.25/.25.0	.25/.25.0	.25/.25/5	.25/25/5	.25/25/5	.25/25/5							3
TECH. ASSIST.				1.0/1.0/1.0	1.0/1.0/1.0	1.0/1.0/1.0	1.0/1.0/1.0							6
MECHANIC		2.0/2.0.0	2.0/2.0.0	1.0/1.0/1.0	1.0/1.0/1.0	1.0/1.0/1.0	1.0/1.0/1.0			5.0/2.0/2.0				23
INST. TECH.		2.0/2.0.0	2.0/2.0.0	1.0/1.0/1.0	1.0/1.0/1.0	1.0/1.0/1.0	1.0/1.0/1.0							14
ELECT. OPER.		0.5/0.5.0	0.5/0.5.0	2.0/2.0.0	2.0/2.0.0	2.0/2.0.0	2.0/2.0.0			3.0/1.0/1.0				19
COMP. OPER.		.25/.25.0	.25/.25.0	.25/.25/5	.25/25/5	.25/25/5	.25/25/5							3
LABORER		0.5	0.5	0.5	0.5	0.5	0.5							2
SECURITY	1.0/1.0/1.0	1.0/1.0.0	1.0/1.0.0											7
												10		10
											Subtotal			87
					</									

**Table 5: Operations and Maintenance Staff Rates & Annual Cost**

Skill	Qty.	\$/Hour	Fringed	Annual \$	Total \$
Project Engineers	18	\$19.00	\$30.40	\$63,232	\$1,138,176
Test Engineers	9	\$19.00	\$30.40	\$63,232	\$569,088
Instrument Engineers	6	\$19.00	\$30.40	\$63,232	\$379,392
Controls Engineers	3	\$19.00	\$30.40	\$63,232	\$189,696
Computer Scientists	7	\$17.00	\$27.20	\$56,576	\$396,032
Facility Engineers-Mechanical	4	\$19.00	\$30.40	\$63,232	\$252,928
Facility Engineers-Electrical	4	\$19.00	\$30.40	\$63,232	\$252,928
Facility Engineers-Computer/ADP	4	\$19.00	\$30.40	\$63,232	\$252,928
Craft Supervisors	4	\$15.00	\$24.00	\$49,920	\$199,680
Technical Assistants	7	\$11.00	\$17.60	\$36,608	\$256,256
Mechanics	26	\$14.00	\$22.40	\$46,592	\$1,211,392
Instrument Technicians	18	\$14.00	\$22.40	\$46,592	\$838,656
Electricians/Operators	22	\$14.00	\$22.40	\$46,592	\$1,025,024
Computer Operators	4	\$10.00	\$16.00	\$33,280	\$133,120
Laborers	3	\$8.00	\$12.80	\$26,624	\$79,872
Totals	139				\$7,175,168

**Table 6: Support Staff Rates & Annual Cost**

Skill	Qty	\$/Hour	Fringed	Annual \$	Total \$
Institutional/Janitorial	5	\$11.00	\$17.60	\$36,608	\$183,040
Security	8	\$12.00	\$19.20	\$39,936	\$319,488
Machine shop	6	\$15.00	\$24.00	\$49,920	\$299,520
Records	2	\$13.00	\$20.80	\$43,264	\$86,528
Communications	1	\$12.00	\$19.20	\$39,936	\$39,936
Library/Configuration Control	3	\$12.00	\$19.20	\$39,936	\$119,808
Photo	2	\$12.00	\$19.20	\$39,936	\$79,872
Safety/Environmental	1	\$16.00	\$25.60	\$53,248	\$53,248
Design/Drafting	6	\$18.00	\$28.80	\$59,904	\$359,424
QA/Calibrations	5	\$19.00	\$30.40	\$63,232	\$316,160
Clerical	8	\$11.00	\$17.60	\$36,608	\$292,864
Totals	47				\$2,149,888

**Table 7: Administrative Staff Rates & Annual Cost**

Skill	Qty	\$/Hour	Fringed	Annual \$	Total \$
General Manager	1	\$45.00	\$72.00	\$149,760	\$149,760
Supervisor	5	\$38.00	\$60.80	\$126,464	\$632,320
Personnel Office	2	\$19.00	\$30.40	\$63,232	\$126,464
Procurement	3	\$17.00	\$27.20	\$56,576	\$169,728
Business Office	3	\$17.00	\$27.20	\$56,576	\$169,728
Totals	14				\$1,248,000

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**COST BASELINE**

**PRODUCTIVITY**

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2

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## **PRODUCTIVITY**

Wind tunnel productivity is dependent upon many parameters and there are many diverse opinions concerning figures of merit to use. For productivity assessments for the NWTC, it is imperative to establish definitions, parameters, benchmarks, and assumptions to have a common basis for comparison. The productivity assessment process is a four step process: (1) develop the NWTC concept and component and/or system arrangement and configuration, (2) develop the facility benchmark test program including test objectives, test type, and test matrix, (3) develop the facility operational plans including the NWTC management philosophy and staffing, and (4) develop the assessment tools.

The NWTC concept and component and/or system arrangement and configuration is discussed in Attachment 2.2 - Technical Description. The facility operational plans and staffing are provided in the previous section - Facility Staffing. This section provides the benchmark test program and the productivity assessments.

The productivity measures of merit used are:

Polar per Occupancy Hour - A polar is defined as a single run containing 25 variations of the independent variable. Occupancy hour is defined as the time between starting to move the model into the tunnel from the buildup area until it is returned to the buildup area.

Test Throughput - Throughput is defined as the number of polars per year that can be achieved for the benchmark test and a given test shift scenario (e. g., 3-shifts per day, 5 - days per week). Throughput combined with the Polars per Occupancy hour effect how fast models must be built-up and made ready for testing.



**TSWT Baseline Test Program**

Test Objective: Optimum configuration development; high supersonic cruise

Mount: Pitch strut

Instrumentation: Internal balance, 300 pressures

Mach # Schedule: A: 0.5, 0.7, 0.8, 0.825, 0.85, 0.9, 0.95 (7 runs)

Pitch Angle Schedule: A: 0, -10, -8, -6, -4, -2, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20, 22, 0 (25 Points)  
B: 0, -4, -3, -2, -1, 0, 1, 2, 3, 4, 0 (11 Points)  
C: 0, 4, 8, 12 (4 Points)

Yaw Angle Data: Obtained at +5 and +10 on baseline and every 10 configurations

**National Wind Tunnel Complex - Cost Baseline**  
**Productivity/Operating Cost/Life Cycle Cost**    December 13, 1993

**Table 2: TSWT Test Plan**

Configuration	Pt, psia	Mach #	Pitch	Yaw	Roll	Runs (Polars)	Cum. Points
Baseline	9	A	B	0	0	1-7	1-77
Baseline	9	A	B	0	180	8-14	78-154
Baseline	9	A	A	0	0	15-21	155-329
Baseline	9	A	C	+5	0	22-28	330-357
Baseline	9	A	C	+10	0	29-35	358-385
Baseline	15	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	36-70	386-770
Baseline	37	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	71-105	771-1,155
Baseline	60	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	106-140	1,156-1,540
Baseline	75	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	141-175	1,541-1,925
Config. 1	60	A	A	0	0	176-182	1,926-2,100
Config. 2-9	60	Same As Runs 176-182	Same As Runs 176-182	Same As Runs 176-182	Same As Runs 176-182	183-238	2,101-3,500
Config. 10	60	A	A	0	0	239-245	3,501-3,675
Config. 10	60	A	C	+5	0	246-252	3,676-3,703
Config. 10	60	A	C	+10	0	253-259	3,704-3,731
Config. 11-80	Same As Runs 239-259	Same As Runs 239-259	Same As Runs 239-259	Same As Runs 239-259	Same As Runs 239-259	260-1,729	3,732-19,901
Config. 81	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	1,730-1,890	19,902-21,672
Config. 82	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	1,891-2,051	21,673-23,443

### PRODUCTIVITY ASSESSMENT

The assessment of the facility productivity was determined through the use of a mathematical representation of the two wind tunnels and some aspects of the auxiliary process systems. The productivity model developed was a first order approximation. It should be noted that this was a preliminary model based on the current knowledge and assumptions for the system configuration. The productivity model should be periodically updated to reflect the changes to the facility configuration as the design matures. In addition, this model is based upon a single test plan. The productivity model should be expanded to include the entire facility and then it should be rigorously exercised for numerous types of test programs. In addition, the productivity requirements should be expanded to include an annual throughput, or, polars per year requirement.

The basic assumptions used in the model development were:

1. The input parameters are provided in the attached pages.
2. The test demand is such that there is at least a steady flow of test models available, if not a backlog.
3. Ambient temperature operation for both wind tunnels
4. The benchmark test program is representative of a developmental aerodynamic test with parameter variations which exercise the tunnel and auxiliary systems through a reasonable range of their capability. Each test matrix obtains a baseline data set at five total pressures from 9 to 75 psia.

Provided in the attached pages are the following items:

1. Productivity model input data sheet for the LSWT
2. Productivity model output for the LSWT
2. Productivity model output for the TSWT

These sheets are merely to reflect how the productivity was determined. -There was significantly more effort aimed at determining the NWTC productivity than what is apparent here.

A summary of the results of the productivity assessment are provided in: 1) Table 1 provides a summary of the Benchmark Test Program, (2) Table 2 provides a summary of the NWTC Operational Profile, and (3) Table 3 provides the quantitative results.

Productivity Study Case Identification		INUM	5						
LSWT Sample Case		Current							
Input Item Description	Input Item Name	Value	Units	Data Table					
				1	2	3	4	5	
Tunnel Isolated Volume	TUN_VOL	2750000	ft <sup>3</sup>	2750000	2750000	2750000	2750000	2750000	
Plenum Isolated Volume	PLEN_VOL	220000	ft <sup>3</sup>	220000	220000	220000	220000	220000	
Test Section Area	TS_AREA	480	ft <sup>2</sup>	480	480	480	480	480	
Maximum Pitch Rate	MAX_PITCH	3	deg/sec	3	3	3	3	3	
Maximum Roll Rate	MAX_ROLL	5	deg/sec	5	5	5	5	5	
Pitch/Roll Acceleration Allowance	ACCEL_ALLOW	15	%	15	15	15	15	15	
Pitch/Roll Deceleration Allowance	DECEL_ALLOW	15	%	15	15	15	15	15	
Model Attitude Pause Time	PAUSE	1	sec	1	1	1	1	1	
Data Acquisition Time	DATA_ACQ	1	sec	1	1	1	1	1	
Sting Deflection Adjustment Time	DEFLECT_ADJ	0.25	sec	0.25	0.25	0.25	0.25	0.25	
Mach Number Control Method	MACH_CNTRL	unchoked	text	unchoked	unchoked	unchoked	unchoked	unchoked	
Choked Minimum Stabilization Time after a Mach Change	CHOKED_STAB	4	sec	4	4	4	4	4	
Unchoked Minimum Stabilization Time after a Mach Change	UNCHOKED_STAB	8	sec	8	8	8	8	8	
Tunnel Temperature Setpoint	TEMP	580	deg R	580	580	580	580	580	
Test Section Cart Speed	TS_CART_SPD	1	ft/sec	1	1	1	1	1	
Test Section Cart Track Length	TS_TRACK_LNGTH	100	ft	100	100	100	100	100	
Plenum Cart Speed	PLEN_CART_SPD	0.5	ft/sec	0.5	1	0.5	0.5	0.5	
Plenum Cart Track Length	PLEN_TRACK_LNGTH	200	ft	200	200	200	200	200	
Isolation Valve Stroke Time	ISO_VALVE_TIME	300	sec	300	300	300	300	300	
Maximum Power Change Rate	MAX_PWR_RATE	50	mw/min	50	50	50	50	50	
Maximum Power Step	MAX_PWR_STEP	0	mw	0	0	0	0	0	
Minimum Fan Wind-Up Time	FAN_WIND_UP	30	sec	30	30	30	30	30	
Minimum Fan Wind-Down Time	FAN_WIND_DWN	90	sec	90	90	90	90	90	
Temperature Stabilization Time	TEMP_STAB	60	sec	60	60	60	60	60	
Tunnel Unlock Time	TUNNEL_UNLOCK	90	sec	90	90	90	90	90	
Open Plenum Shell Door Time	PLEN_DOOR_OPN	60	sec	60	60	60	60	60	
Open Test Section Door Time	TS_DOOR_OPN	60	sec	60	60	0	0	0	
Work Platform Installation Time	WORK_PLAT_INST	360	sec	360	0	360	360	360	
Time to Reach Position on Work Platform	TO_WORK_PLAT	120	sec	120	120	120	120	120	
Model Change Time	MODEL_CHANGE	600	sec	600	900	1200	1500	1800	
Time to Leave Work Platform	FROM_WORK_PLAT	120	sec	120	120	120	120	120	
Work Platform Removal Time	WORK_PLAT_REM	360	sec	360	360	360	360	360	
Test Section Closure Procedure Time	TS_CLOSE	60	sec	60	60	60	60	60	
Plenum Door Closure Time	PLEN_CLOSE	60	sec	60	60	60	60	60	
Time to Comply with Pre-run Procedures	PRERUN_PROC	120	sec	120	120	120	120	120	
Instrumentation Hookup Time	INSTR_HOOKUP	600	sec	600	600	600	600	600	
Instrumentation Verification Time	INSTR_VERIFY	600	sec	600	600	600	600	600	
Time to Secure Plenum	PLEN_SECURE	60	sec	60	60	60	60	60	
Air Supply Storage Pressure	STOR_PRESS	300	psea	300	300	300	300	300	
Air Supply Storage Volume	STOR_VOL	134000	ft <sup>3</sup>	134000	134000	134000	134000	134000	
Air Supply Compressor Mass Flow Rate	SUPP_COMP_FLOW	275	lbm/sec	275	275	275	275	275	
Isolation Equalization Valve Cv	ISOL_VALVE_CV	22000	(standard)	22000	22000	22000	22000	22000	
Vacuum Sphere Setpoint Pressure	SPHERE_PRESS	1	psea	1	1	1	1	1	
Vacuum Sphere Volume	SPHERE_VOL	67000	ft <sup>3</sup>	67000	67000	67000	67000	67000	
Vacuum System Compressor Mass Flow Rate	VAC_COMP_FLOW	2000	ft <sup>3</sup> /sec	2000	2000	2000	2000	2000	
Tunnel Evacuation Valve Cv	TUN_EVAC_VAL_CV	54000	(standard)	54000	54000	54000	54000	54000	
Tunnel Vent Valve Cv	TUN_VENT_VAL_CV	99000	(standard)	99000	99000	99000	99000	99000	
Plenum Evacuation Valve Cv	PLEN_EVAC_VAL_CV	99000	(standard)	99000	99000	99000	99000	99000	
Plenum Vent Valve Cv	PLEN_VENT_VAL_CV	99000	(standard)	99000	99000	99000	99000	99000	
Mass adjustment during Mach changes	ADJUST_VALVE_CV	5000	(standard)	5000	5000	5000	5000	5000	
PES Compressor Efficiency	PES_COMP_EFF	80	%	80	80	80	80	80	
PES Control Valve % Total Pressure Loss	PES_VALVE_LOSS	20	%	20	20	20	20	20	
% Unscheduled Maintenance Time	UNSCH_MAINTEN	2	%	2	2	2	2	2	
% Scheduled Maintenance Time	SCH_MAINTEN	5	%	5	5	5	5	5	
Shift Hours per Week	SHIFT_HRS_WK	80	hrs	80	80	80	80	80	
Output Item Description	Output Item Name	Output	Units	Output					
				Output	Output	Output	Output	Output	
Occupancy Hours	OCCUP_HOURS	203.76	hr	203.76	201.10	226.71	239.45	252.21	203.76
Drive-On Hours	DRIVE_ON_HOURS	79.33	hr	79.33	79.33	79.33	79.33	79.33	79.33
Shift Hours	SHIFT_HOURS	213.95	hr	213.95	211.18	238.05	251.42	264.82	213.95
Total Runs	TOTAL_RUNS	1290		1290	1290	1290	1290	1290	1290
Total Points	TOTAL_PTS	23670		23670	23670	23670	23670	23670	23670
Polars per Occupancy Hour	POLARS_OCC_HR	6.33	polars/hr	6.33	6.41	5.69	5.39	5.11	6.33
Polars per Drive-On Hour	POLARS_DO_HR	16.26	polars/hr	16.26	16.26	16.26	16.26	16.26	16.26

## Main Sequence File

### Productivity Study Case Identification LSWT Sample Case

#### PITCH-ROLL SERIES DEFINITIONS

PRSERIES-1: BETA=0/ALPHA-A ; BETA=5/ALPHA-B ; BETA=10/ALPHA-B

PRSERIES-2: BETA=0/ALPHA-A

#### MACH SERIES DEFINITIONS

MACH-A: M = 0.20, 0.25

CONFIGURATION ACTIVITY		OCCUPANCY HOURS	DRIVE-ON HOURS	RUNS	POINTS
	MOVE TEST SECTION TO W/T	0.16	0.00	0	0
	HOOKUP INSTRUMENTATION	0.33	0.00	0	0
BASELINE	STARTUP TO PT=9	0.12	0.03	0	0
BASELINE	RUN MACH-A/PRSERIES-1,PT=9	0.19	0.19	6	98
BASELINE	CHANGE PT: 9 TO 15	0.08	0.08	0	0
BASELINE	RUN MACH-A/PRSERIES-1,PT=15	0.19	0.19	6	98
BASELINE	CHANGE PT: 15 TO 37	0.28	0.28	0	0
BASELINE	RUN MACH-A/PRSERIES-1,PT=37	0.19	0.19	6	98
BASELINE	CHANGE PT: 37 TO 60	0.30	0.30	0	0
BASELINE	RUN MACH-A/PRSERIES-1,PT=60	0.19	0.19	6	98
BASELINE	CHANGE PT: 60 TO 75	0.19	0.19	0	0
BASELINE	RUN MACH-A/PRSERIES-1,PT=75	0.19	0.19	6	98
BASELINE	SHUTDOWN FROM PT=75	0.12	0.03	0	0
CONFIG1	ACCESS MODEL	0.56	0.00	0	0
CONFIG1	STARTUP TO PT=75	0.17	0.03	0	0
CONFIG1	RUN MACH-A/PRSERIES-1,PT=75	0.19	0.19	6	98
CONFIG1	CHANGE PT: 75 TO 60	0.19	0.19	0	0
CONFIG1	RUN MACH-A/PRSERIES-2,PT=60	0.05	0.05	2	50
CONFIG1	SHUTDOWN FROM PT=60	0.12	0.03	0	0
repeat CONFIG1 149 times (2-150)		191.54	73.26	1192	22052
CONFIG151	STARTUP TO PT=9	0.12	0.03	0	0
CONFIG151	RUN MACH-A/PRSERIES-1,PT=9	0.19	0.19	6	98
CONFIG151	CHANGE PT: 9 TO 15	0.08	0.08	0	0
CONFIG151	RUN MACH-A/PRSERIES-1,PT=15	0.19	0.19	6	98
CONFIG151	CHANGE PT: 15 TO 37	0.28	0.28	0	0
CONFIG151	RUN MACH-A/PRSERIES-1,PT=37	0.19	0.19	6	98

CONFIG151	CHANGE PT: 37 TO 60	0.30	0.30	0	0
CONFIG151	RUN MACH-A/PRSERIES-1,PT=60	0.19	0.19	6	98
CONFIG151	CHANGE PT: 60 TO 75	0.19	0.19	0	0
CONFIG151	RUN MACH-A/PRSERIES-1,PT=75	0.19	0.19	6	98
CONFIG151	SHUTDOWN FROM PT=75	0.12	0.03	0	0
CONFIG152	STARTUP TO PT=9	0.12	0.03	0	0
CONFIG152	RUN MACH-A/PRSERIES-1,PT=9	0.19	0.19	6	98
CONFIG152	CHANGE PT: 9 TO 15	0.08	0.08	0	0
CONFIG152	RUN MACH-A/PRSERIES-1,PT=15	0.19	0.19	6	98
CONFIG152	CHANGE PT: 15 TO 37	0.28	0.28	0	0
CONFIG152	RUN MACH-A/PRSERIES-1,PT=37	0.19	0.19	6	98
CONFIG152	CHANGE PT: 37 TO 60	0.30	0.30	0	0
CONFIG152	RUN MACH-A/PRSERIES-1,PT=60	0.19	0.19	6	98
CONFIG152	CHANGE PT: 60 TO 75	0.19	0.19	0	0
CONFIG152	RUN MACH-A/PRSERIES-1,PT=75	0.19	0.19	6	98
CONFIG152	SHUTDOWN FROM PT=75	0.12	0.03	0	0
	DISCONNECT INSTRUMENTATION	0.17	0.00	0	0
	MOVE TEST SECTION TO BUILDUP	0.16	0.00	0	0
		TEST HOURS	DRIVE-ON HOURS	RUNS	POINTS
TEST TOTALS:		199.77	79.33	1290	23670
UNSCHEDULED MAINTENANCE:		4.00			
OCCUPANCY HOURS:		203.76			
WEEKS RUN:		2.55			
SCHEDULED MAINTENANCE:		10.19			
TOTAL SHIFT HOURS:		213.95			
POLARS PER OCCUPANCY HOUR:		6.33			
POLARS PER DRIVE-ON HOUR:		16.26			

## Main Sequence File

### Productivity Study Case Identification TSWT Sample Case

#### PITCH-ROLL SERIES DEFINITIONS

PRSERIES-1: ROLL=0/ALPHA-B; ROLL=180/ALPHA-B; BETA=0/ALPHA-A;  
BETA=5/ALPHA-C; BETA=10/ALPHA-C

PRSERIES-2: BETA=0/ALPHA-A

PRSERIES-3: BETA=0/ALPHA-A; BETA=5/ALPHA-C; BETA=10/ALPHA-C

#### MACH SERIES DEFINITIONS

MACH-A: M=0.5,0.7,0.8,0.825,0.85,0.9,0.95

CONFIGURATION ACTIVITY		OCCUPANCY HOURS	DRIVE-ON HOURS	RUNS	POINTS
	MOVE TEST SECTION TO W/T	0.16	0.00	0	0
	HOOKUP INSTRUMENTATION	0.33	0.00	0	0
BASLINE	STARTUP TO PT=9	0.09	0.02	0	0
BASLINE	RUN MACH-A/PRSERIES-1,PT=9	0.69	0.69	35	413
BASLINE	CHANGE PT: 9 TO 15	0.02	0.02	0	0
BASLINE	RUN MACH-A/PRSERIES-1,PT=15	0.69	0.69	35	413
BASLINE	CHANGE PT: 15 TO 37	0.09	0.09	0	0
BASLINE	RUN MACH-A/PRSERIES-1,PT=37	0.69	0.69	35	413
BASLINE	CHANGE PT: 37 TO 60	0.09	0.09	0	0
BASLINE	RUN MACH-A/PRSERIES-1,PT=60	0.70	0.70	35	413
BASLINE	CHANGE PT: 60 TO 75	0.06	0.06	0	0
BASLINE	RUN MACH-A/PRSERIES-1,PT=75	0.70	0.70	35	413
BASLINE	SHUTDOWN FROM PT=75	1.87	0.02	0	0
CONFIG1	ACCESS MODEL	0.89	0.00	0	0
CONFIG1	STARTUP TO PT=60	0.12	0.02	0	0
CONFIG1	RUN MACH-A/PRSERIES-2,PT=60	0.19	0.19	7	175
CONFIG1	SHUTDOWN FROM PT=60	1.62	0.02	0	0
CONFIG2	ACCESS MODEL	0.89	0.00	0	0
CONFIG2	STARTUP TO PT=60	0.12	0.02	0	0
CONFIG2	RUN MACH-A/PRSERIES-2,PT=60	0.19	0.19	7	175
CONFIG2	SHUTDOWN FROM PT=60	1.62	0.02	0	0
CONFIG3	ACCESS MODEL	0.89	0.00	0	0
CONFIG3	STARTUP TO PT=60	0.12	0.02	0	0
CONFIG3	RUN MACH-A/PRSERIES-2,PT=60	0.19	0.19	7	175
CONFIG3	SHUTDOWN FROM PT=60	1.62	0.02	0	0
CONFIG4	ACCESS MODEL	0.89	0.00	0	0

CONFIG4	STARTUP TO PT=60	0.12	0.02	0	0
CONFIG4	RUN MACH-A/PRSERIES-2,PT=60	0.19	0.19	7	175
CONFIG4	SHUTDOWN FROM PT=60	1.62	0.02	0	0
CONFIG5	ACCESS MODEL	0.89	0.00	0	0
CONFIG5	STARTUP TO PT=60	0.12	0.02	0	0
CONFIG5	RUN MACH-A/PRSERIES-2,PT=60	0.19	0.19	7	175
CONFIG5	SHUTDOWN FROM PT=60	1.62	0.02	0	0
CONFIG6	ACCESS MODEL	0.89	0.00	0	0
CONFIG6	STARTUP TO PT=60	0.12	0.02	0	0
CONFIG6	RUN MACH-A/PRSERIES-2,PT=60	0.19	0.19	7	175
CONFIG6	SHUTDOWN FROM PT=60	1.62	0.02	0	0
CONFIG7	ACCESS MODEL	0.89	0.00	0	0
CONFIG7	STARTUP TO PT=60	0.12	0.02	0	0
CONFIG7	RUN MACH-A/PRSERIES-2,PT=60	0.19	0.19	7	175
CONFIG7	SHUTDOWN FROM PT=60	1.62	0.02	0	0
CONFIG8	ACCESS MODEL	0.89	0.00	0	0
CONFIG8	STARTUP TO PT=60	0.12	0.02	0	0
CONFIG8	RUN MACH-A/PRSERIES-2,PT=60	0.19	0.19	7	175
CONFIG8	SHUTDOWN FROM PT=60	1.62	0.02	0	0
CONFIG9	ACCESS MODEL	0.89	0.00	0	0
CONFIG9	STARTUP TO PT=60	0.12	0.02	0	0
CONFIG9	RUN MACH-A/PRSERIES-2,PT=60	0.19	0.19	7	175
CONFIG9	SHUTDOWN FROM PT=60	1.62	0.02	0	0
CONFIG10	ACCESS MODEL	0.89	0.00	0	0
CONFIG10	STARTUP TO PT=60	0.12	0.02	0	0
CONFIG10	RUN MACH-A/PRSERIES-3,PT=60	0.43	0.43	21	259
CONFIG10	SHUTDOWN FROM PT=60	1.62	0.02	0	0
repeat CONFIG 1 thru 10 seven times		199.49	17.80	588	12838
CONFIG81	ACCESS MODEL	0.89	0.00	0	0
CONFIG81	STARTUP TO PT=9	0.09	0.02	0	0
CONFIG81	RUN MACH-A/PRSERIES-3,PT=9	0.42	0.42	21	259
CONFIG81	CHANGE PT: 9 TO 15	0.02	0.02	0	0
CONFIG81	RUN MACH-A/PRSERIES-3,PT=15	0.42	0.42	21	259
CONFIG81	CHANGE PT: 15 TO 37	0.09	0.09	0	0
CONFIG81	RUN MACH-A/PRSERIES-3,PT=37	0.43	0.43	21	259
CONFIG81	CHANGE PT: 37 TO 60	0.09	0.09	0	0
CONFIG81	RUN MACH-A/PRSERIES-3,PT=60	0.43	0.43	21	259
CONFIG81	CHANGE PT: 60 TO 75	0.06	0.06	0	0
CONFIG81	RUN MACH-A/PRSERIES-3,PT=75	0.43	0.43	21	259
CONFIG81	SHUTDOWN FROM PT=75	1.87	0.02	0	0
CONFIG82	ACCESS MODEL	0.89	0.00	0	0
CONFIG82	STARTUP TO PT=9	0.09	0.02	0	0

CONFIG82	RUN MACH-A/PRSERIES-3,PT=9	0.42	0.42	21	259
CONFIG82	CHANGE PT: 9 TO 15	0.02	0.02	0	0
CONFIG82	RUN MACH-A/PRSERIES-3,PT=15	0.42	0.42	21	259
CONFIG82	CHANGE PT: 15 TO 37	0.09	0.09	0	0
CONFIG82	RUN MACH-A/PRSERIES-3,PT=37	0.43	0.43	21	259
CONFIG82	CHANGE PT: 37 TO 60	0.09	0.09	0	0
CONFIG82	RUN MACH-A/PRSERIES-3,PT=60	0.43	0.43	21	259
CONFIG82	CHANGE PT: 60 TO 75	0.06	0.06	0	0
CONFIG82	RUN MACH-A/PRSERIES-3,PT=75	0.43	0.43	21	259
CONFIG82	SHUTDOWN FROM PT=75	1.87	0.02	0	0
	DISCONNECT INSTRUMENTATION	0.17	0.00	0	0
	MOVE TEST SECTION TO BUILDUP	0.16	0.00	0	0
		TEST HOURS	DRIVE-ON HOURS	RUNS	POINTS
TEST TOTALS:		245.02	29.01	1057	19327
UNSCHEDULED MAINTENANCE:		4.90			
OCCUPANCY HOURS:		249.92			
WEEKS RUN:		49.98			
SCHEDULED MAINTENANCE:		12.50			
TOTAL SHIFT HOURS:		262.42			
POLARS PER OCCUPANCY HOUR:		4.23			
POLARS PER DRIVE-ON HOUR:		36.43			

**Table 1: Summary of Benchmark Test Program**

- Objective: Configuration Development
- Instrumentation: Balance plus 300 pressures

PARAMETER	LSWT	TSWT
Mach Number Variations	2	7
Pitch Angles		
$\alpha$ polar, $\beta = 0^\circ$	25	25
$\alpha$ polar, $\beta = 5^\circ$ and $10^\circ$	11	4
Total Pressure Variations		
Baseline Configuration	5	5
Development Configurations	2	1
Configurations	153	83
Polars	1290	1022
Equivalent 25 point polars	894	732
Points	22,350	18,298

**Table 2: NWTTC Operational Profile**

Shift	Sun	Mon	Tues	Wed	Thurs	Fri	Sat
1	A	O	O	O	O	O	A
2	A	O	O	O	O	O	M
3	A	O	O	O	O	O	A

O = Operational  
 240 Operational Days per Year  
 10 Holidays per year  
 10 days of unscheduled maintenance per year  
 M = Maintenance - two 4- hour periods per weekend  
 A = Unscheduled Time

**Table 3: Summary of Results of Productivity Assessment**

	LSWT			TSWT		
Fan-on Time	7.2 hours per day	1,728 hours per year	6.1 hours per day	1,464 hours per year		
Fan on/off cycles	19.5 per day	4,680 per year	20.7 per day	4,968 per year		
Pitch Polars (25 points per polar)	115 per day	27,600 per year	184.5 per day	44,280 per year		
Model Configuration Changes (tunnel entries)	19.5 per day	4,680 per year	20.7 per day	4,968 per year		
Model Installations and Removals	Every 8 days	30 per year	Every 4 days	60 per year		

5 Polars per Occupancy Hour

8 Polars per Occupancy Hour

Based on: 240 Operational Days per Year and 3 Shifts per Day



**COST BASELINE**  
**OPERATING COST**

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**OPERATING COST**

The operating cost for the NWTC is a direct function of the staffing levels, the benchmark test program, and the facility productivity. Using the staffing levels and productivity results provided in the previous sections in conjunction with the performance requirements outlined in the Technical Description (Attachment 2.2), the annual cost to operate the NWTC was determined. The second issue associated with the operating cost is to determine the cost per polar. This is one of the measures of merit that will be used by potential users to assess if this facility will be economically appropriate for them to use. The overall goal is to improve the productivity and system efficiency with a commensurate reduction in the cost per polar.

The assumptions used in the assessment of the annual operating cost were:

1. NWTC staffing level is 200 full time personnel.
2. Three shift per day operation for 5 days per week.
3. Two 4-hour periods per week are allotted for routine maintenance. This was assumed to occur on weekends.
4. Two weeks throughout the year were allotted for unscheduled maintenance.
5. Two weeks throughout the year were allotted for holidays.
6. Annual maintenance costs were assumed to be 0.35% of the capital construction cost of the NWTC.
7. Annual capital improvement costs were assumed to be approximately 0.5% of the capital construction cost of the NWTC.
8. Utility rates were based on National Averages:

Electricity	\$47 per MWHour
Natural Gas	\$0.0047 per cubic foot
Water and Sewage	\$1.53 per cubic foot

The results of the operating cost assessment are shown in Tables 1 and 2. The cumulative utility usage is provided in Table 1. The cumulative usage values were determined from the Productivity model discussed in the previous section. The staffing costs were determined using a combination of the staffing plan presented previously in conjunction with the staffing required to implement the benchmark test program. The annual operating cost is provided in Table 2.

**Table 1: Cumulative Operating Cost Parameters**

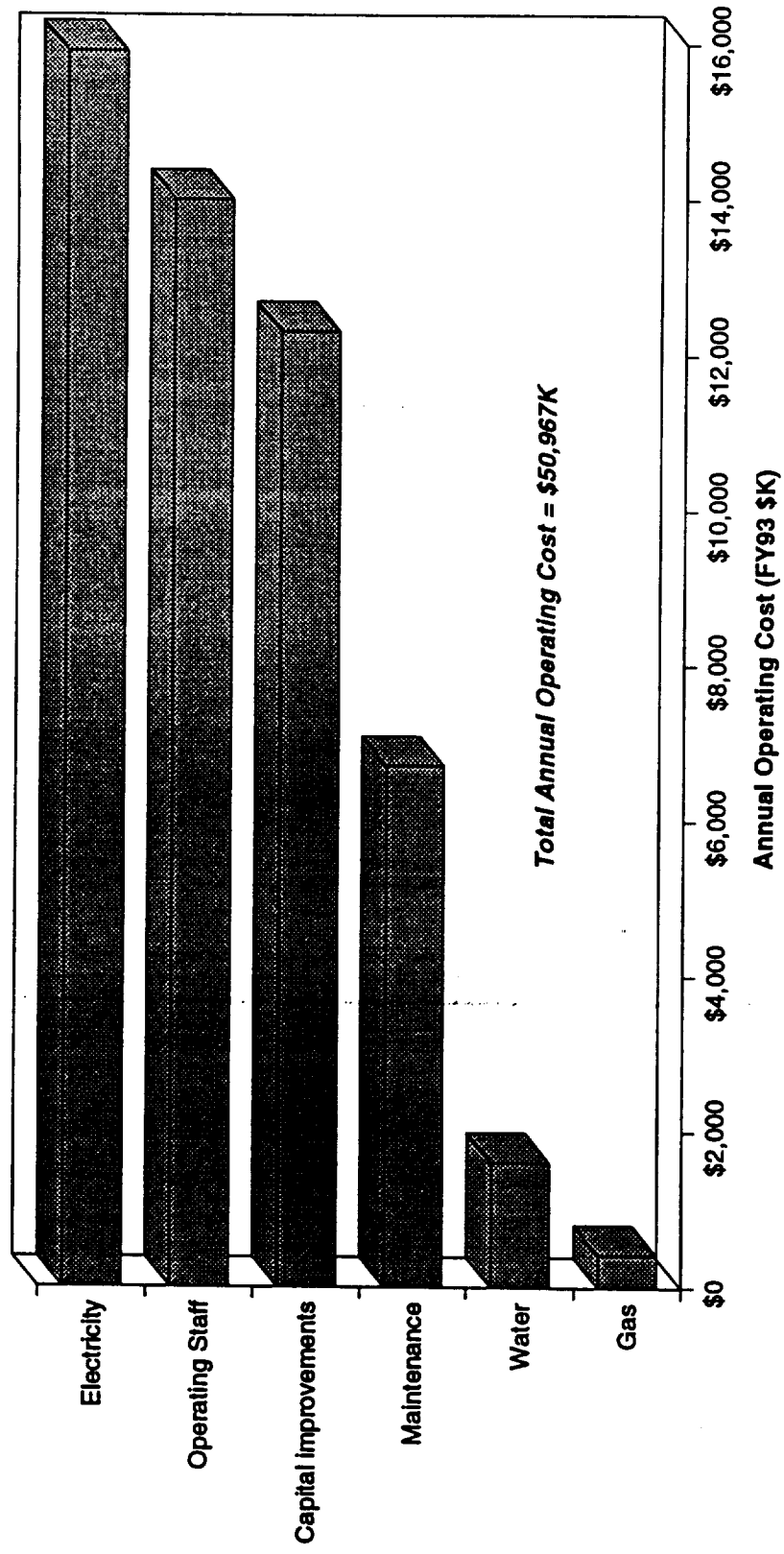
Parameter	LSWT	TSWT
Polars per occupancy hour	5	8
Polars per fan on hour	16	30
Occupancy hrs per week	120	120
Operational months per year	11	11
Maximum drive power (KHP)	90	310
Average power per test (MW)	41.3	142.2
Total polars per year	28,598	45,756
Total occupancy hours	5,720	5,720
Total energy per month (MWH)	6,710	19,722
Total energy per year (MWH)	73,807	216,939
Total gas per year (cubic ft)	38,124,335	51,367,525
Total water and sewage( cubic ft)	11,656,882	93,234,585

**Table 2: Annual Operating Cost Summary (FY93 \$K)**

PARAMETER	LSWT	TSWT	ANNUAL TOTAL
Operating Staff	\$7,000	\$7,000	\$14,000
Maintenance	\$3,358	\$3,358	\$6,715
Capital improvements	\$6,152	\$6,152	\$12,305
Electricity	\$4,597	\$11,324	\$15,921
Gas	\$210	\$210	\$421
Water	\$178	\$1,426	\$1,605
<b>Totals</b>	<b>\$21,496</b>	<b>\$29,471</b>	<b>\$50,967</b>
Total polars	28,598	45,756	
Cost per polar (\$)	\$752	\$644	

# NATIONAL WIND TUNNEL COMPLEX - COST BASELINE

Figure 1: Annual Operating Cost Component Comparison



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**COST BASELINE**  
**LIFE CYCLE COST**

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## LIFE CYCLE COST

### Description

The purpose of this Life Cycle Cost (LCC) analysis is two fold. It is to meet the requirements of all analyses submitted to the Office of Management and Budget (OMB) in support of legislative and budget programs and, if significant discriminators appear, it may be useful in the selection process from among the proposed concepts.

This LCC analysis for the NWTC has been performed in accordance with the criteria for a **Cost-Effectiveness Analysis** as prescribed by OMB Circular A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs." Consideration was given to incorporating the Department of Energy guidelines for LCC analysis, but this was not adopted because the concepts being evaluated are not alternative strategies based on energy conservation or costs.

OMB Circular A-94, Appendix C (updated February 25, 1993), is the source for the discount rates used in this analysis. In accordance with Circular A-94, an alternative assumption for the rate of inflation is used instead of the recommended Gross Domestic Product deflator (currently 2.2%); for this analysis the rate of inflation, or escalation rate, used is that recommended by the Corps of Engineers for civil works activities (currently 3.5%).

### Methodology

This LCC analysis is a present value comparison based on 1993 dollars, which is also the basis for most elements of the project cost estimate. Other than during the operational life cycle, costs or values not expressed in '93 dollars will be converted using the escalation rate for the time value of money.

The start of operation of the wind tunnels is assumed to be October 1, 2003, and the costs of operation have been assumed for fifty (50) years beyond that date. Costs are adjusted to the start of operation using the escalation rate and the analysis for the operational period is based on constant dollars.

The LCC analysis is performed on Microsoft Excel and the present value of all operational costs is determined at the start of operations date using the XNPV tool. The rate used for this factor is a real discount rate (currently 4.5%) and three periods of analysis are used: thirty(30), forty (40), and fifty (50) years.

The first analysis assumes that all concepts have the same date for the start of operations. If subsequent analyses involve different schedules for each concept, the present value of all operational periods occurring later will be adjusted to the date of the earliest using a nominal discount rate (currently 6.7%). This

difference in discount rate reflects the alternative use of money by the Government for the differential period(s).

The present value of operational costs at the start of operations is adjusted to current dollars using the escalation rate as described for all costs/values. The present value for each concept for a given operational period then is the sum of all costs in current dollars.

### **Contents**

The components of cost are considered in the categories of Design, Construction, and Operations.

The design costs are determined as a percentage of the engineering cost estimate for each concept and are considered to be 'FY 94 dollars. These estimates are then adjusted to 'FY 93 dollars. The design costs include Preliminary Engineering Reports, special studies, and final designs.

The construction costs are based on the engineering cost estimate but include adders for profit; bond; supervision, inspection, and engineering services (SIES); and Government project management.

The operational costs include staffing, maintenance, capital improvements, and utilities. Staffing levels are based on the assumption that all necessary labor resources for the operation, management, and one half (50%) of the maintenance effort of the complex are provided for a 3-shift-per-day, 5-day-per-week operating schedule in each tunnel. It is further assumed that scheduled maintenance activities will be performed both during operating shifts and periods between tests and that an integration of responsibilities will allow work crews to perform both operations and maintenance tasks. Also, a high degree of facility automation, centralized control, diagnostic features and operational flexibility is assumed. The staffing levels were developed based on current practices at existing wind tunnel facilities with refinements to reflect technological and productivity improvements. The staffing level is 200 permanent employees and it is assumed to be contractor based. Current costs of \$70,000 per man-year are used.

The model for maintenance and capital improvement costs is based on the 16T/16S Complex at Arnold Engineering Development Center (AEDC) which includes two wind tunnels, an air plant, and a plenum evacuation system. This set of facilities is assumed to be very representative of the proposed new NWTC and their actual maintenance and capital improvement costs are considered representative of a similarly costed new facility.

The AEDC data was obtained in the four categories of labor, materials, maintenance and repair, and improvements and modernization. The

maintenance and capital improvements model assumes that one half (50%) of the labor hours are provided by the facility staff, therefore only half (50%) will be attributed to direct maintenance support. The materials costs are used directly as are the maintenance and repair costs which are considered to be contracts costs. The improvements and modernization costs are used as a annual budget estimate for capital improvements and the assumption is made that there will be additional periodic major improvements. The model uses a \$5M current dollar major improvement every fifth year of operations.

The utilities cost model includes electricity, natural gas, and water consumption. Based on the projected operational profile, the electricity consumption was estimated and costed using the current national average electric rate.

### **Data**

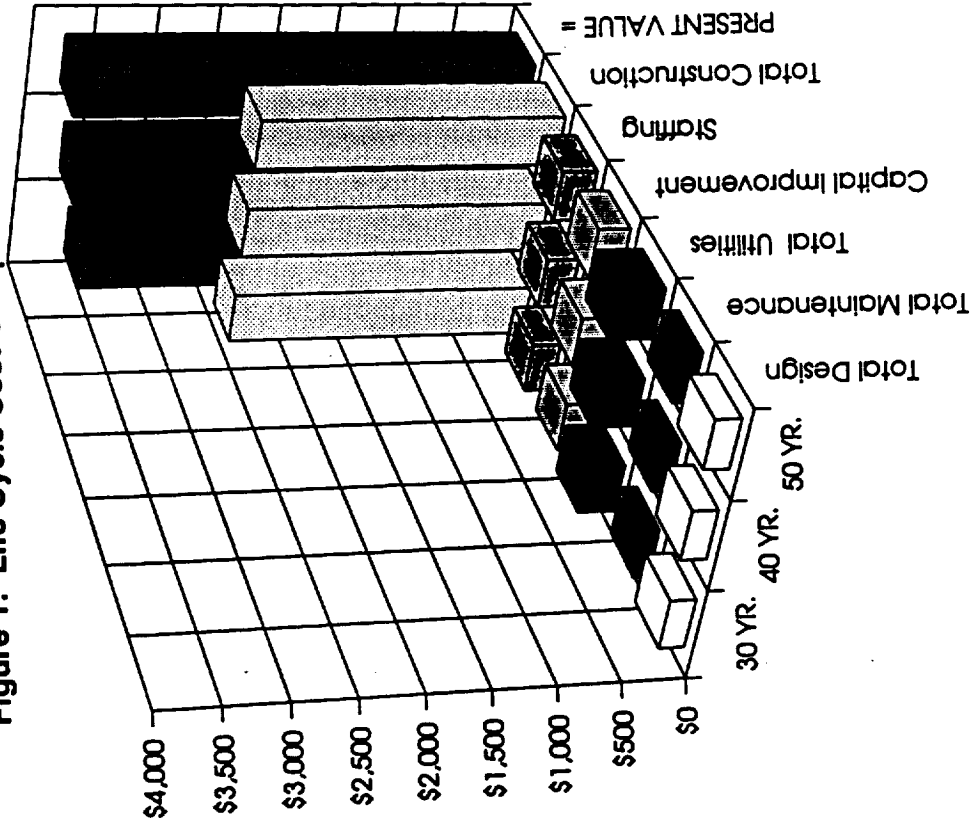
The results of the LCC analysis is shown on the following tables and figures. The data is presented for operational periods of thirty(30), forty (40), and fifty (50) years in the form of both data tables and three dimensional bar charts.

**Table 1: Cost Baseline Life Cycle Cost Assessment**

Category	Facility Life		
	30 YR.	40 YR.	50 YR.
Total Design	\$201	\$201	\$201
Design	\$164	\$164	\$164
Studies	\$37	\$37	\$37
Total Construction	\$2,499	\$2,499	\$2,499
Operations	\$875	\$989	\$1,061
Staffing	\$233	\$263	\$283
Total Maintenance	\$123	\$139	\$149
Labor	\$59	\$66	\$71
Materials	\$20	\$23	\$24
Contracts	\$44	\$50	\$54
Capital Improvement	\$214	\$241	\$259
Total Utilities	\$305	\$345	\$370
Electricity	\$271	\$307	\$329
Gas	\$7	\$8	\$8
Water	\$27	\$31	\$33
PRESENT VALUE =	\$3,576	\$3,689	\$3,762

# NATIONAL WIND TUNNEL COMPLEX - COST BASELINE

Figure 1: Life Cycle Cost Comparison



**ATTACHMENT 3**

**NATIONAL WIND TUNNEL COMPLEX**

**ALTERNATIVE CONCEPTS**

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**ATTACHMENT 3.1**

**NATIONAL WIND TUNNEL COMPLEX**

**ALTERNATIVE CONCEPTS**

**REQUIREMENTS COMPARISON**



# NATIONAL WIND TUNNEL COMPLEX - ALTERNATIVE CONCEPTS REQUIREMENTS COMPARISON

Table 1: Low Speed Wind Tunnel Requirements

Parameter	Concept A	Concept A Modified	Concept B	Concept C	Concept D
<b>Max. Reynolds Number</b>	<b>16.6 Million</b>	<b>16.6 Million</b>	<b>30.6 Million</b>	<b>16.6 Million</b>	<b>20.4 Million</b>
• Mach Range	0.05 to 0.6	0.05 to 0.6	0.05 to 0.6	0.05 to 0.6	0.05 to 0.6
• Chord Length	1.79 ft.	1.79 ft.	1.79 ft.	1.79 ft.	2.19 ft.
• Oper. Press.	0.07 to 5 atm.	0.07 to 5 atm.	0.03 to 5 atm.	0.07 to 5 atm.	0.07 to 5 atm.
• Test Section Size	16 x 20 ft - 288 ft <sup>2</sup>	16 x 20 ft - 288 ft <sup>2</sup>	16 x 20 ft - 288 ft <sup>2</sup>	16 x 20 ft - 288 ft <sup>2</sup>	20 x 24 ft - 432.4 ft <sup>2</sup>
• Fillets	yes	yes	yes	yes	yes
• Max. Temp °F	Ambient +30°	Ambient +30°	-100° to 110°	Ambient +30°	Ambient +30°
• Test Gas	Air	Air	Air	Air	Air
• Drive Power	60,000 hp	60,000 hp	60,000 hp	60,000 hp	90,000 hp
<b>Productivity</b>	<b>3 Polars/OH</b>	<b>5 Polars/OH</b>	<b>5 Polars/OH</b>	<b>5 Polars/OH</b>	<b>5 Polars/OH</b>
• Carts	2 (1 sting and 1 floor)	4 (1 sting, 2 floor, 1 open jet with 35 foot open jet)	5 (1 sting, 2 floor, 1 open jet with 50 foot open jet, and 1 ground belt)	5 (1 sting, 2 floor, 1 open jet with 35 foot open jet, and 1 ground belt)	4 (1 sting, 2 floor, 1 open jet with 35 foot open jet)
• Press. Rate	0.1 atm/min	0.1 atm/min	0.2 atm/min	0.1 atm/min	0.1 atm/min
<b>Flow Quality</b>					
• Temp. Distr.	±1.5°F	±1.0°F	±1.0°F	±1.0°F	±1.0°F
• Turbulence, %	0.08	longitudinal - 0.04 vertical - 0.08 lateral - 0.08	longitudinal - 0.04 vertical - 0.08 lateral - 0.08	longitudinal - 0.04 vertical - 0.08 lateral - 0.08	longitudinal - 0.04 vertical - 0.08 lateral - 0.08
• Noise	50.6 dB	59.4 dB	59.4 dB	59.4 dB	59.4 dB
• Stream Angle Deviation	±0.1°	±0.1°	±0.1°	±0.1°	±0.1°
• Stream Angle Gradient	0.12°(2σ)	0.01°/foot	0.01°/foot	0.01°/foot	0.01°/foot
• Static Press.	0.25%q	0.1%q			
• Dynamic Pressure			±0.1%	±0.1%	
<b>Anechoic Chamber</b>	<b>No</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>

**Table 2: Transonic Speed Wind Tunnel Requirements**

Parameter	Concept A	Concept A Modified	Concept B	Concept C	Concept D
<b>Max. Reynolds Number</b>	<b>27.7 Million</b>	<b>28.2 Million</b>	<b>41 Million</b>	<b>28.2 Million</b>	<b>28.2 Million</b>
• Mach Range	0.1 to 1.3	0.05 to 1.3	0.05 to 1.6	0.05 to 1.5	0.05 to 1.5
• Chord Length	1.31 ft.	1.31 ft.	1.31 ft.	1.31 ft.	1.31 ft.
• Oper. Press.	0.07 to 5 atm.	0.07 to 5 atm.	0.03 to 8 atm.	0.07 to 5 atm.	0.07 to 5 atm.
• Test Section Size	11 x 15.5 ft - 158 ft <sup>2</sup>	11 x 15.5 ft - 158 ft <sup>2</sup>	11 x 15.5 ft - 170.5 ft <sup>2</sup>	11 x 15.5 ft - 170.5 ft <sup>2</sup>	11 x 15.5 ft - 170.5 ft <sup>2</sup>
• Fillets	yes	yes	no	no	no
• Max. Temp °F	Ambient +30°	Ambient +30°	Nominal 100°F	Ambient +30°	Ambient +30°
• Test Gas	Air	Air	Air	Air	Air
• Drive Power	260,000 hp	260,000 hp	295,000 hp	295,000 hp	295,000 hp
• Nozzle	Fixed	Fixed	Flexible, Complex	Flexible, Complex	Flexible, Simple
<b>Productivity</b>	<b>10 Polars/DH</b>	<b>8 Polars/OH</b>	<b>8 Polars/OH</b>	<b>8 Polars/OH</b>	<b>8 Polars/OH</b>
• Carts	2 (1 sting and 1 floor)	4 (2 sting, 1 floor, and 1 acoustic)	4 (2 sting, 1 floor, and 1 acoustic)	4 (2 sting, 1 floor, and 1 acoustic)	4 (2 sting, 1 floor, and 1 acoustic)
• Press. Rate	0.1 atm/min	0.1 atm/min	0.2 atm/min	0.1 atm/min	0.1 atm/min
<b>Flow Quality</b>					
• Temp. Distr.	±1.5°F	±1.0°F	±1.0°F	±1.0°F	±1.0°F
• Turbulence, %	0.15	longitudinal - 0.04 vertical - 0.08 lateral - 0.08	longitudinal - 0.04 vertical - 0.08 lateral - 0.08	longitudinal - 0.04 vertical - 0.08 lateral - 0.08	longitudinal - 0.04 vertical - 0.08 lateral - 0.08
• Noise	10-30 dB>Boeing's	95 dB	95 dB	95 dB	95 dB
• Stream Angle Deviation	±0.1°	±0.1°	±0.1°	±0.1°	±0.1°
• Stream Angle Gradient	0.15°(2σ)	±0.1°	0.01°/foot	0.01°/foot	0.01°/foot
• Mach # Distribution	0.0015°(2σ)	±0.001	±0.001 subsonic ±0.01 supersonic	±0.001 subsonic ±0.01 supersonic	±0.001 subsonic ±0.01 supersonic

Concept A-Modified had 5 options assessed. These options consisted of variations of either wind tunnel. The Concept A-Modified Baseline requirements are identified in Table 1 (LSWT) and Table 2 (TSWT) above. The Concept A-Modified Options requirements are identified in Table 3. Only the changes are noted in Table 3, requirements not identified in Table 3 are still the Concept A-Modified Baseline requirements.

**Table 3: Requirements Comparison for the Concept A-Modified Options**

Wind Tunnel	A-Mod. Option 1	A-Mod. Option 2	A-Mod. Option 3	A-Mod. Option 4	A-Mod. Option 5
LSWT					
• Temp. Range	Min. Temp=-100°F	Baseline LSWT	Baseline LSWT	50' Open Jet	Min. Temp=-40°F
• Open Jet Length				Baseline TSWT	Baseline TSWT
TSWT	Baseline TSWT	0.05 to 1.6 Flexible, Complex	0.07 to 8 atm. 260,000 hp		
• Mach Range					
• Nozzle					
• Ops. Pressure					
• Drive Power					

Concept D had 8 options assessed. These options consisted of variations of either wind tunnel. The Concept D-Baseline requirements are identified in Table 1 (LSWT) and Table 2 (TSWT) above. The Concept D-Options requirements are identified in Table 3. Only the changes are noted in Table 3, requirements not identified in Table 3 are still the Concept D-Baseline requirements.

**Table 4: Requirements Comparison for the Concept D-Options**

D-Baseline	D Option 1	D Option 2	D Option 3	D Option 4
<b>LSWT</b> • 20 x 24 ft. Test Section • No Fillets • Slotted Walls <b>TSWT</b> • 11 x 15.5 ft. Test Section • Mmax = 1.5 • Flex Nozzle, Simple • 2-Stage Compressor • Injection Augmentation for >M=1.3 Ops.	<b>LSWT</b> Test Section Fillets Less Drive Power  <b>TSWT</b> Baseline	<b>LSWT</b> Test Section Fillets -20°F Ops.  <b>TSWT</b> Baseline	<b>LSWT</b> Baseline  <b>TSWT</b> 2-Stage Compressor Injection Augmentation Flex Nozzle, Complex	
	<b>D Option 5</b>	<b>D Option 6</b>	<b>D Option 7</b>	<b>D Option 8</b>
	<b>LSWT</b> Test Section Fillets Less Drive Power  <b>TSWT</b> 3-Stage Compressor No Injection Augmentation	<b>LSWT</b> Test Section Fillets Less Drive Power  <b>TSWT</b> 3-Stage Compressor No Injection Augmentation Flex Nozzle, Complex	<b>LSWT</b> Test Section Fillets -20°F Ops.  <b>TSWT</b> 3-Stage Compressor No Injection Augmentation	<b>LSWT</b> Test Section Fillets -20°F Ops.  <b>TSWT</b> 3-Stage Compressor No Injection Augmentation Flex Nozzle, Complex

**ATTACHMENT 3.2**

**NATIONAL WIND TUNNEL COMPLEX**

**ALTERNATIVE CONCEPTS**

**TECHNICAL DESCRIPTIONS**

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## NATIONAL WIND TUNNEL COMPLEX

### Technical Description Comparisons

#### Cost Baseline Wind Tunnel Complex (Concept D - Option 5):

- A Low Speed Wind Tunnel (LSWT) provides for efficient high Reynolds Number testing (20 million, at the drive power design point, with semi-span models) at Mach Numbers from 0.05 to 0.6, total pressures from 0.07 to 5 atm., and at ambient operating temperatures. The centerline dimensions of the LSWT are 459-ft. long x 96-ft. wide. The LSWT has a 104-ft. dia. settling chamber with flow conditioning devices to provide outstanding flow quality. A 51-ft dia. x 59-ft. long movable plenum section is used to facilitate the interchange of test sections and models. The LSWT has three interchangeable test section types: an open jet test section with an integral model support system, a filleted 20-ft. x 24-ft. closed, variable, and ventilated test section with floor mounted model support system (2), and a filleted 20-ft. x 24-ft. closed, variable, and ventilated test section with a rear sting mounted model support. The Concept D LSWT circuit has acoustically treated turning vanes in corners #1 and #4, and acoustic treatment in the fan nacelle and fan casing areas. The tunnel has acoustic testing capabilities at 1 atmosphere in the open jet test configuration, with a large anechoic room built into the outer plenum shroud. Aerodynamic requirements to optimize flow quality in the test section: local pressure deviations of  $< 0.25\%$ , local flow angularity of  $< \pm 0.10^\circ$ , local temperature deviations of  $\pm 1.0^\circ\text{F}$ , and turbulence intensities of  $< 0.08\%$  (0.04% in the longitudinal direction). The LSWT drive system consists of a single stage, low RPM compressor, with 12 fixed composite blades, variable inlet and outlet guide vanes, a 90,000 hp. electric motor drive, and variable frequency drive controls. Integrated controls and test data acquisition systems are provided for fully automated execution of test sequences, including automated start up and shut down of auxiliaries and comprehensive tunnel process monitoring with diagnostics. The LSWT is being designed for high productivity requirements (5 polars/hr.).
- A Transonic Wind Tunnel (TSWT) provides for efficient, high Reynolds Number testing (30 million, with semi-span models; 40 million, with full-span models; either at the drive power design point) at Mach Numbers from 0.1 to 1.5, total pressures from 0.07 to 5 atm., and at ambient operating temperatures. The centerline dimensions of the TSWT are 295-ft. long x 88-ft. wide. The TSWT has a 51-ft. dia. settling chamber with flow conditioning devices to provide outstanding flow quality. A 38-ft. dia. x 50-ft. long movable plenum section is used to facilitate the interchange of test sections and models. The TSWT has one 11-ft. x 15.5-ft. closed test section with an integral floor mounted model support system, and two 11-ft. x 15.5-ft. test closed test sections with an integral rear strut model support systems. The

TSWT uses a plenum evacuation system to increase the test section Mach Number by removal of mass flow (5% of tunnel mass flow) through slotted or perforated walls in the test section. Aerodynamic requirements to optimize flow quality in the test section: local pressure deviations of  $< 0.25\%$ , local flow angularity of  $< \pm 0.10^\circ$ , local temperature deviations of  $\pm 1.0^\circ\text{F}$ , and turbulence intensities of  $< 0.15\%$ . The TSWT drive system consists of a three stage, low RPM compressor, with 31 composite blades per stage, two rows of variable inlet and outlet guide vanes, a 295,000 hp. electric motor drive, and variable frequency drive controls. Integrated controls and test data acquisition systems are provided for fully automated execution of test sequences, including automated start up and shut down of auxiliaries and comprehensive tunnel process monitoring with diagnostics. The TSWT is being designed for high productivity requirements (8 polars/hr.).

- A generic (favorable but not unrealistic) 60 acre site is required with systems provided for electrical power, utilities, buildings, and auxiliary systems to support two wind tunnels. The site work includes all excavation, finish grading, drainage, paving, roads, parking lots, associated area lighting, and landscaping. Electrical power requirements include two independent power sources in the range of 115 kv. to 230 kv., depending on the electric power company. Medium and low voltage substations will provide power at 4.16 kv. and 480 volts. The total estimated power levels are 510 MW total connected load, 400 MW peak demand load, and 300 MW average demand load. Other electrical systems include lighting, communications, security, and miscellaneous protection and monitoring systems. Utilities required include natural gas supply, potable water supply, storm and sanitary waste water collection systems, fire protection, compressed air system, and telephone service. The buildings include model preparation areas and a model shop/warehouse for both the LSWT and TSWT, as well as tunnel environmental enclosures, tunnel operations areas, specialized equipment buildings, and office areas for personnel. The layout of the tunnels is end to end using a common drive building. Drive motors are not shared.

Separate model cart rooms are used for each tunnel and model carts are not shared. Auxiliary systems include wind tunnel pressurization and vacuum systems, model propulsion air, and a cooling water system. The complex includes facilities for systematically checking and calibrating in a hierarchical manner all functional components, subsystems, and the complete system/facility.

## CARTS - DEFINITIONS

<b>Movable Plenum Cart</b>	The movable plenum cart is the plenum pressure shell, which translates in and out of the tunnel circuit on rails. It contains one of four test section cart types and is used for rapid interchange of rear sting or floor mounted models pre-installed in the test section carts. The plenum cart transports the test section carts from the cart bays to the tunnel and supports the test section carts during tunnel operation.
<b>Test Section Carts</b>	The test section carts are the test section internal components, consisting of movable walls, model support systems and support structure. These carts are adapted and made interchangeable for different modes of testing. The four basic test types used are: (1) Rear Sting Mount Testing (internal balances), (2) Floor Mount Testing (external balances), (3) Moving Ground Belt Testing, and (4) Open Jet Testing. Models are installed in test section carts and fully checked out in cart rooms in advance of tunnel installation. The test section carts are of modular design in Concept A and of integral design in all other concepts.
<b>Rear Sting Cart</b>	The rear sting cart accommodates a sting mounted model from a vertical strut system with pitch and roll capability. The rear sting cart includes four test section walls (movable sidewalls), and integral roller truck assemblies. It rolls between cart bays and movable plenum with quick disconnect power and data cabling.
<b>Floor Mount Cart</b>	The floor mount cart accommodates a full pod mounted or semi-span floor mounted model. The model support systems are connected to a floor mounted external balance system. Includes pitch and yaw capability and includes four walls (movable sidewalls), and integral roller truck assemblies. Rolls between cart bays and movable plenum with quick disconnect power and data cabling.
<b>Acoustic Open Jet Cart</b>	The acoustic open jet cart is used with an anechoic chamber permanently built into the tunnel. It provides an acoustic testing capability for atmospheric test conditions. Acoustic models are either sting or pylon mounted. In Concept A Mod and Concept C, the pylon model can be traversed. In Concept B, the longer jet length removes the need for the model traverse. Used in the LSWT only.

**Moving Ground  
Belt Cart**

The moving ground belt cart is similar to rear sting cart, except floor is a moving ground belt, and rear stings are connected to an articulated strut with pitch and yaw capability. Rolls between cart bays and movable plenum with quick disconnect power and data cabling. Used in the LSWT only.

## COMPARISON OF TECHNICAL DESCRIPTIONS

### Concept A

The Concept A Wind Tunnel Complex requires the following changes from Concept D:

The LSWT has a 16 x 20 foot test section versus the 20 x 24 foot test section. This results in all tunnel dimensions being smaller. The tunnel volume is about 60% of the Concept D internal volume (and therefore shell weight). The additional effect is the reduction in the maximum tunnel Reynolds number from 20 Million to 16.6 Million. The fan drive power requirement also reduces due to the smaller test section to 60,000 hp from 90,000 hp. The LSWT does not have the acoustic testing capabilities. Acoustic turning vanes are not used, neither is the acoustic treatment on the fan nacelle. The LSWT uses modular carts versus integral carts. Therefore, twice the number of model buildup bays are required to accommodate the additional cart pieces. The quantity of the carts is reduced from 4 to 2. The tunnels are parallel versus end to end. This minimizes the amount of future expansion capability for increasing the number of model build-up bays. The flow quality requirements are somewhat less stringent.

The TSWT does not have the acoustic testing capability. The TSWT uses modular carts versus integral carts. The quantity of carts is reduced from 4 to 2. The TSWT maximum speed is 1.3 versus 1.5. This means the nozzle is a fixed nozzle versus a flexible nozzle. The flexible nozzle sub-system is no longer required. The nozzle length is also about 40 feet shorter, with the resulting reduction in the tunnel internal volume and shell weight. This revises the tunnel compressor needs to a 2-stage compressor versus a three-stage compressor to achieve the Mach Numbers >1.3.

### Concept A-Modified

The Concept A-Modified Wind Tunnel Complex requires the following changes from Concept D:

The LSWT has a 16 x 20 foot test section versus the 20 x 24 foot test section. This results in all tunnel dimensions being smaller. The tunnel volume is about 60% of the Concept D internal volume (and therefore shell weight). The additional effect is the reduction in the maximum tunnel Reynolds number from 20 Million to 16.6 Million. The fan drive power requirement also reduces due to the smaller test section to 60,000 hp from 90,000 hp.

The TSWT maximum speed is 1.3 versus 1.5. This means the nozzle is a fixed nozzle versus a flexible nozzle. The flexible nozzle sub-system is no longer required. The nozzle length is also about 40 feet shorter, with the resulting reduction in the tunnel internal volume and shell weight. This revises the tunnel

compressor needs to a 2-stage compressor versus a three-stage compressor to achieve the Mach Numbers  $>1.3$ .

### **Concept C**

The Concept C Wind Tunnel Complex requires the following changes from Concept D:

The LSWT has a 16 x 20 foot test section versus the 20 x 24 foot test section. This results in all tunnel dimensions being smaller. The tunnel volume is about 60% of the Concept D internal volume (and therefore shell weight). The additional effect is the reduction in the maximum tunnel Reynolds number from 20 Million to 16.6 Million. The fan drive power requirement also reduces due to the smaller test section to 60,000 hp from 90,000 hp. One additional test section cart is added - the Moving Ground Belt Cart.

The TSWT uses a complex flexible nozzle versus a simplified flexible nozzle. The use of the complex nozzle should result in the ability to achieve the required flow quality with respect to the Mach Number Gradients and Deviations. The change is the use of approximately 15 actuator stations for flexing the nozzle versus two or three actuator stations. The additional actuator stations complicate the Mach number control system.

### **Concept B**

The Concept B Wind Tunnel Complex requires the following changes from Concept D:

The LSWT has a 16 x 20 foot test section versus the 20 x 24 foot test section. This results in all tunnel dimensions being smaller. The tunnel volume is about 60% of the Concept D internal volume (and therefore shell weight). The operating temperature range is changed to  $-100^{\circ}\text{F}$  to  $110^{\circ}\text{F}$  versus ambient  $+30^{\circ}\text{F}$ . This causes the tunnel shell and all internals to be changed to stainless steel. This is a significant cost increase. The tunnel heat exchanger system is radically different using a 2-stage refrigerant system with a dedicated refrigerant plant and cooling tower. The low pressure air system requirement essentially doubles partly due to the doubling of the shell pressurization rate to 0.2 atmospheres per minute and also due to the additional mass of air required due to the colder temperatures. The model preparation area for the LSWT is revised to provide a conditioned environment to allow access to the model either cold or with very dry air.. The drive power design point stays the same but with the smaller test section the drive system power reduces to 60,000 hp. One additional cart is added - the Moving Ground Belt Cart. All of the test section carts need to be fabricated from stainless steel. The ability for the model support systems to move accurately and rapidly is significantly complicated due to the use of the cold environment.

The TSWT maximum operating pressure increases to 8 atmospheres versus 5 atmospheres. The drive power design point does not change. The maximum tunnel speed is increased to Mach 1.6 versus Mach 1.5. A complex flexible nozzle is used in lieu of the simplified flexible nozzle. The use of the complex nozzle should result in the ability to achieve the required flow quality with respect to the Mach Number Gradients and Deviations. The change is the use of approximately 15 actuator stations for flexing the nozzle versus two or three actuator stations. The additional actuator stations complicate the Mach number control system.

**Table 1 Comparison of Cart Types and Quantities**

	CONCEPT A	CONCEPT A (MODIFIED)	CONCEPT B	CONCEPT C	CONCEPT D
LSWT	1 Plenum Cart	1 Plenum Cart	2 Plenum Carts	1 Plenum Cart	1 Plenum Cart
	3 - Test Section Carts (Modular Design)	4 - Test Section Carts (Integral Design)	5 - Test Section Carts (Integral Design)	5 - Test Section Carts (Integral Design)	4 - Test Section Carts (Integral Design)
	1 - Rear Sting Cart (3 Pieces)	1 - Rear Sting Cart	1 - Rear Sting Cart	1 - Rear Sting Cart	1 - Rear Sting Cart
	1 - Floor Mount Cart (3 Pieces)	2 - Floor Mount Carts	2 - Floor Mount Carts	2 - Floor Mount Carts	2 - Floor Mount Carts
	1 - Open Jet Cart (4 Pieces) (Mounts Inside Plenum Cart)	1 - Acoustic Open Jet Cart (Requires No Plenum Cart)	1 - Acoustic Open Jet Cart (Requires No Plenum Cart)	1 - Acoustic Open Jet Cart (Requires No Plenum Cart)	1 - Acoustic Open Jet Cart (Requires No Plenum Cart)
			1 - Moving Ground Plane Cart	1 - Moving Ground Plane Cart	
TSWT	1 - Plenum Cart	1 - Plenum Cart	1 - Plenum Cart	1 - Plenum Cart	1 - Plenum Cart
	2 - Test Section Carts (Modular Design)	4 - Test Section Carts (Integral Design)	4 - Test Section Carts (Integral Design)	4 - Test Section Carts (Integral Design)	4 - Test Section Carts (Integral Design)
	1 - Rear Sting Cart (3 Pieces)	2 - Rear Sting Carts	2 - Rear Sting Carts	2 - Rear Sting Carts	2 - Rear Sting Carts
	1 - Floor Mount Cart (3 Pieces)	1 - Floor Mount Cart	1 - Floor Mount Cart	1 - Floor Mount Cart	1 - Floor Mount Cart
		1 - Acoustic Closed Jet Cart	1 - Acoustic Closed Jet Cart	1 - Acoustic Closed Jet Cart	1 - Acoustic Closed Jet Cart

**ATTACHMENT 3.3**

**NATIONAL WIND TUNNEL COMPLEX**

**ALTERNATIVE CONCEPTS**

**CAPITAL COST COMPARISONS**

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## **NATIONAL WIND TUNNEL COMPLEX ALTERNATIVE CONCEPTS - CAPITAL COST COMPARISON**

The capital costs between the alternative concepts are identified here. The cost estimating methodology used for the alternative concepts was identical for what was used for the cost baseline. Provided herein are the cost estimates to the second tier. As with the cost baseline cost estimate, the costs were developed at the fourth and fifth tiers. However, only the first and second tier costs are shown here in the interests of brevity. The detailed fourth and fifth tier cost estimates are available if required. The comparisons between the concepts are provided in Table 1. The comparisons between the Concept A-Modified Options are provided in Table 2. The comparisons between the Concept D Options are provided in Table 3.

The cost estimates developed are the program costs for the project. The costs include all elements necessary to provide a fully functioning complex. The cost estimates were developed based on the assumption of multi-tiering of contracts. The basic cost estimating assumptions used were:

1. The cost estimates were based upon a single prime contractor for the construction.
2. The Prime construction contractor would subcontract all elements of work. The cost estimates were developed based upon the idea that the actual element cost occurred at either the third or fourth tier. The costs developed are for a subcontractor to perform the work. The subcontractor costs include the price to perform the work including labor, materials, rentals, transportation, and shipping, overhead, general and administrative expenses, taxes, and profit.
3. The prime contractor costs to procure the work elements and to manage and administer the overall construction activities are included in WBS 8000. The prime contractor costs for labor, materials, offices, travel, overhead, general and administrative expenses, and taxes are include.
4. A cost risk, expressed as a percentage of the engineering estimate was assigned to each WBS work element to reflect the confidence level in the estimate. The construction cost estimate then was the engineering cost plus the risk factor.  
Risk factors considered were:
  - The maturity of the design (schematic or pre-design, sketch refinement and basic parameters, preliminary drawings and specifications, or working drawings and specifications) and cost risk parameters such as certainty of requirements
  - Cost risk parameters such as certainty of requirements and site conditions
  - Complexity of the project such as the type of design (fixed principle design, adaptive design, or original design)
5. The design costs to produce the design and integrate the design into a system were estimated for each WBS. The design services estimated were for "build to print" or performance specifications for those items that would be design/build contracts.

6. The following items were added to the produce the Total Construction Budget Estimate:
  - Profit of 10% of the WBS subtotal (2nd Tier) for the Prime Contractor
  - Bond of 1% for the Prime Contractor
  - Cost adjustment for inflation to the mid-point of construction (7 years from the July 1, 1993 estimate date) at 3.5% per year. The 3.5% was based on the Army Corps of Engineers recommendations.
  - Project Contingency of 10%
  - Supervision, Inspection, and Engineering Services (SIES) at 8%.
7. Additional costs for the PER, studies, final design, and Government Project Management were included to provide the final Program Budget.

**Table 1 Capital Cost Comparisons for Alternative Concepts**  
(All Costs in \$K)

Work Breakdown Structure	Concept A	Concept A- Mod	Concept B	Concept C	Concept D
1000 Site and Infrastructure	\$56,354	\$55,620	\$68,001	\$56,484	\$59,739
2000 Buildings	\$79,297	\$82,490	\$89,801	\$82,490	\$102,452
3000 Aux. Process Systems	\$108,642	\$129,480	\$257,346	\$130,036	\$156,973
4000 LSWT	\$227,286	\$258,040	\$490,558	\$280,040	\$473,777
5000 TSWT	\$262,116	\$309,165	\$415,962	\$364,241	\$341,207
7000 Operations	\$82,279	\$105,013	\$128,453	\$107,379	\$106,479
8000 Mgmt. and Support	\$186,660	\$195,829	\$282,330	\$207,525	\$200,611
Engineering Estimate	\$1,002,635	\$1,135,637	\$1,732,451	\$1,228,195	\$1,441,238
Risk	\$216,899	\$284,866	\$538,251	\$315,744	\$350,254
<b>Sub-Total</b>	<b>\$1,219,534</b>	<b>\$1,420,503</b>	<b>\$2,270,703</b>	<b>\$1,543,940</b>	<b>\$1,791,492</b>
Profit (10%)	\$121,953	\$142,050	\$227,070	\$154,394	\$179,149
Bond (1%)	\$13,415	\$15,626	\$24,978	\$16,983	\$19,706
Escalation (3.5%/yr)	\$365,824	\$426,108	\$681,143	\$463,136	\$537,394
Contingency (10%)	\$172,073	\$200,429	\$320,389	\$217,845	\$252,774
SIES (8%)	\$151,424	\$220,472	\$352,428	\$239,630	\$222,441
<b>Total Construction Cost</b>	<b>\$2,044,222</b>	<b>\$2,425,187</b>	<b>\$3,876,711</b>	<b>\$2,635,928</b>	<b>\$3,002,956</b>
PER	\$40,884	\$48,504	\$77,534	\$52,719	\$60,059
Government Proj. Mgmt.	\$102,961	\$121,488	\$197,426	\$132,604	\$158,762
Studies	\$38,523	\$38,523	\$39,861	\$26,357	\$38,523
Design	\$89,592	\$115,532	\$197,410	\$125,585	\$123,168
<b>Total Budget Cost</b>	<b>\$2,316,183</b>	<b>\$2,749,234</b>	<b>\$4,388,942</b>	<b>\$2,973,192</b>	<b>\$3,384,168</b>

**Table 2 Capital Cost Comparisons for Concept A-Modified Options**  
(All Costs in \$K)

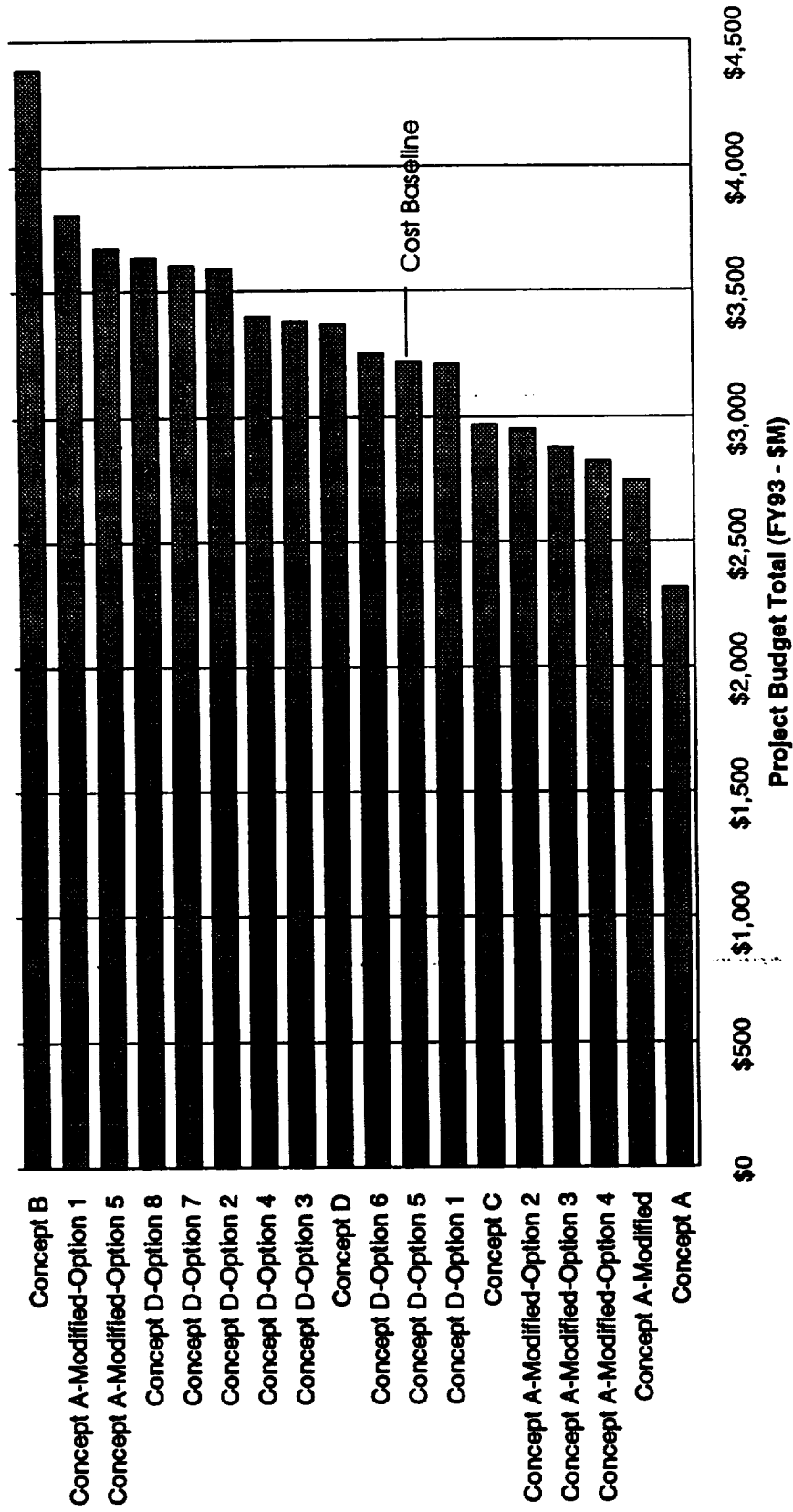
Work Breakdown Structure	Concept A-Mod Base	Option 1	Option 2	Option 3	Option 4	Option 5
1000 Site and Infrastructure	\$55,620	\$67,100	\$55,920	\$55,620	\$55,620	\$64,459
2000 Buildings	\$82,490	\$87,592	\$82,490	\$82,490	\$85,854	\$82,530
3000 Aux. Process Systems	\$129,480	\$249,579	\$132,592	\$129,480	\$129,480	\$214,987
4000 LSWT	\$258,040	\$431,377	\$258,040	\$258,040	\$275,639	\$432,662
5000 TSWT	\$309,165	\$309,165	\$376,210	\$347,381	\$310,613	\$309,165
7000 Operations	\$105,013	\$119,804	\$106,689	\$107,396	\$105,013	\$119,804
8000 Mgmt. and Support	\$195,829	\$252,689	\$205,918	\$202,460	\$200,465	\$246,537
Engineering Estimate	\$1,135,637	\$1,517,307	\$1,217,859	\$1,182,867	\$1,162,683	\$1,470,235
Risk	\$284,866	\$452,658	\$310,064	\$306,478	\$296,989	\$428,604
Sub-Total	\$1,420,503	\$1,969,965	\$1,527,923	\$1,489,345	\$1,459,672	\$1,898,839
Profit (10%)	\$142,050	\$196,996	\$152,792	\$148,934	\$145,967	\$189,884
Bond (1%)	\$15,626	\$21,670	\$16,807	\$16,383	\$16,056	\$20,887
Escalation (3.5%/yr)	\$426,108	\$590,930	\$458,331	\$446,759	\$437,858	\$569,595
Contingency (10%)	\$200,429	\$277,956	\$215,585	\$210,142	\$205,955	\$267,920
SIES (8%)	\$220,472	\$305,752	\$237,144	\$231,156	\$226,551	\$294,712
Total Construction Cost	\$2,425,187	\$3,363,269	\$2,608,583	\$2,542,719	\$2,492,060	\$3,241,837
PER	\$48,504	\$67,265	\$52,172	\$50,854	\$49,841	\$64,837
Government Proj. Mgmt.	\$121,488	\$170,464	\$131,171	\$127,676	\$124,918	\$163,997
Studies	\$38,523	\$38,523	\$38,523	\$38,523	\$38,523	\$38,523
Design	\$115,532	\$170,482	\$124,091	\$121,369	\$120,687	\$165,938
Total Budget Cost	\$2,749,234	\$3,810,003	\$2,954,539	\$2,881,141	\$2,826,030	\$3,675,132

**Table 3 Capital Cost Comparisons for Concept D Options**  
*(All costs in \$K)*

	Project Total Cost
Concept D - Baseline	\$3,371,432
Concept D - Option 1	\$3,211,760
Concept D - Option 2	\$3,593,249
Concept D - Option 3	\$3,383,064
Concept D - Option 4	\$3,402,984
Concept D - Option 5	\$3,223,392
Concept D - Option 6	\$3,254,944
Concept D - Option 7	\$3,604,881
Concept D - Option 8	\$3,636,433

# NATIONAL WIND TUNNEL COMPLEX

Figure 1: Alternative Concepts - Project Budget Cost



**ATTACHMENT 3.4**

**NATIONAL WIND TUNNEL COMPLEX**

**ALTERNATIVE CONCEPTS**

**PRODUCTIVITY/OPERATING COST/LIFE**

**CYCLE COST COMPARISONS**

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**ALTERNATIVE CONCEPTS**  
**OPERATING COST COMPARISONS**

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## **NATIONAL WIND TUNNEL COMPLEX**

### **Alternative Concepts Operating Cost Comparisons**

The operating cost assessments were performed in the same manner as for the Cost Baseline Operating Cost Assessment. Therefore, only the results of the assessments are provided here. Table 1 depicts the cumulative elements for the Operating cost Utilities and key parameters. Table 2 depicts the total annual operating cost per concept in fiscal year 1993 dollars. Figure 1 is merely a graphical representation of the results of Table 2.

**Table 1: Alternative Concepts Comparisons of Cumulative Operating Cost Elements**

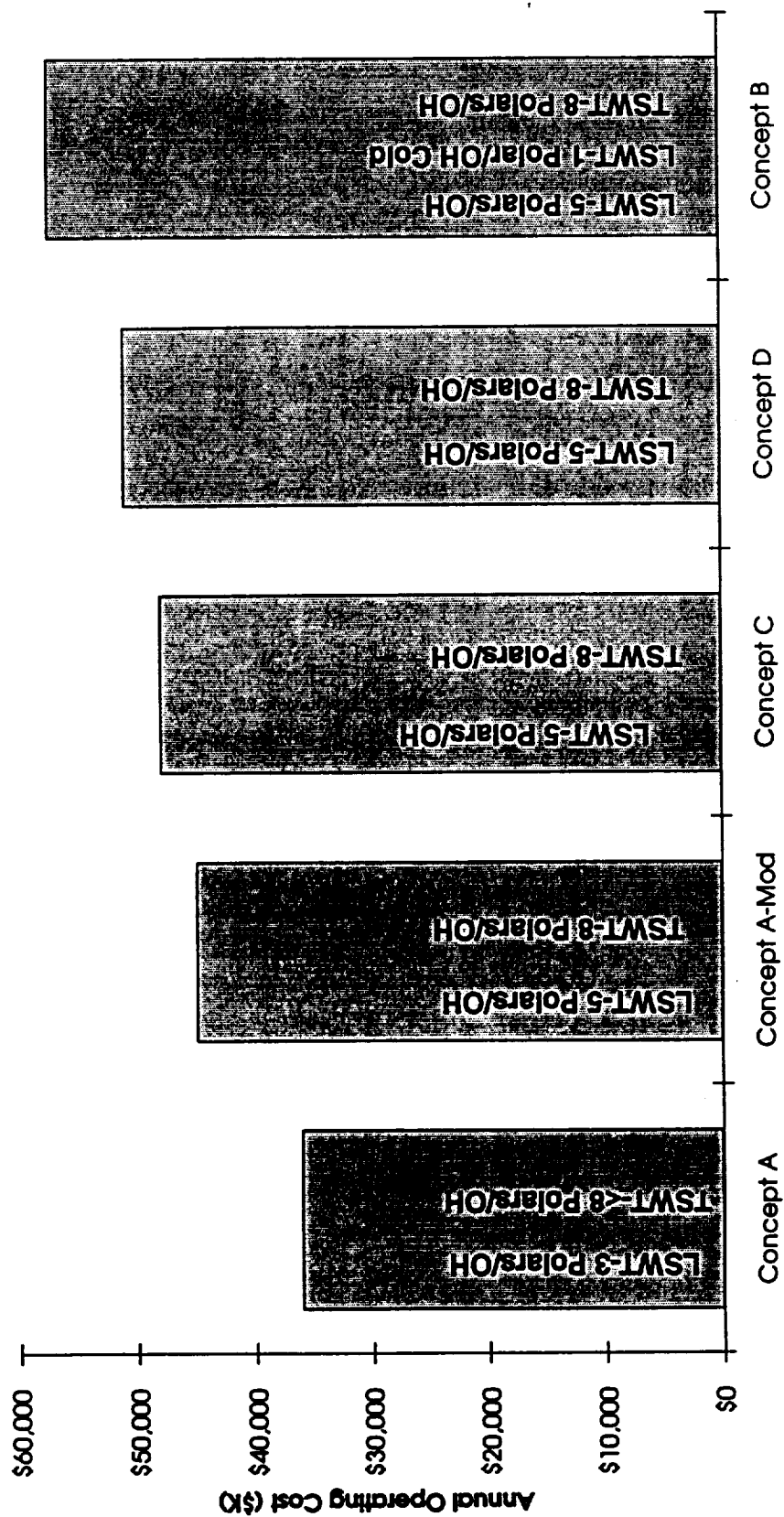
	Concept A		Concept A Modified		Concept B			Concept C		Concept D	
	LSWT	TSWT	LSWT	TSWT	LSWT	LSWT - Cold	TSWT	LSWT	TSWT	LSWT	TSWT
Polars per occupancy hour	3.2	3.8	5	8	5	1	8	5	8	5	8
Polars per fan on hour	16	30	16	30	16	2.5	30	16	30	16	30
Occupancy hrs per week	120	120	120	120	120	120	120	120	120	120	120
Operational months per year	11	11	11	11	8	3	11	11	11	11	11
Maximum drive power (KHP)	60	310	60	310	60	60.00 + 25.96 MW for cooling Power	310	60	310	90	310
Average power per test (MW)	28	142	28	142	28	53.5	142	27.5	142	41	142
Total polars per year	18,303	21,734	28,598	45,756	20,798	1560	45,756	28,598	45,756	28,598	45,756
Total occupancy hours	5720	5720	5720	5720	4160	1560	5720	5720	5720	5720	5720
Total energy per month (MWH)	2,863	9,368	4473	19,722	4,473	12,793	9,722	4473	19,722	6710	19,722
Total energy per year (MWH)	31,491	103,046	49,205	216,939	35,785	38,380	216,939	49,205	216,939	73,807	216,939
Total gas per year (1000 cubic ft)	24,400	24,400	38,124	51,368	27,727	10,819	51,368	38,124	51,368	38,124	51,368
Total water and sewage (1000 cubic ft)	4,974	44,286	7,771	93,235	5,652	6,062	93,235	7,771	93,235	11,657	93,235

**Table 2: Alternative Concepts Comparisons of Operating Cost**  
*(All Costs in FY93 \$. Note these costs are dollars)*

	Concept A	Concept A-Modified	Concept B	Concept C	Concept D
Operating Staff	\$12,880,000	\$14,000,000	\$14,000,000	\$14,000,000	\$14,000,000
Maintenance	\$4,802,500	\$4,996,275	\$8,941,982	\$6,080,004	\$6,715,216
Capital Improvements	\$8,800,000	\$9,155,070	\$16,385,100	\$11,140,872	\$12,304,821
Utilities					
Electricity	\$8,579,239	\$14,764,747	\$15,937,899	\$14,764,747	\$15,921,061
Gas	\$229,356	\$420,612	\$422,595	\$420,612	\$420,612
Water	\$753,678	\$1,545,389	\$1,605,705	\$1,545,389	\$1,604,839
Total Annual Operating Cost	\$36,044,773	\$44,862,093	\$57,293,281	\$47,951,625	\$50,966,549
Cost Per Polar: LSWT	\$876	\$624	\$803-Ambient \$5239-Cold	\$678	\$752
TSWT	\$920	\$591	\$714	\$624	\$644

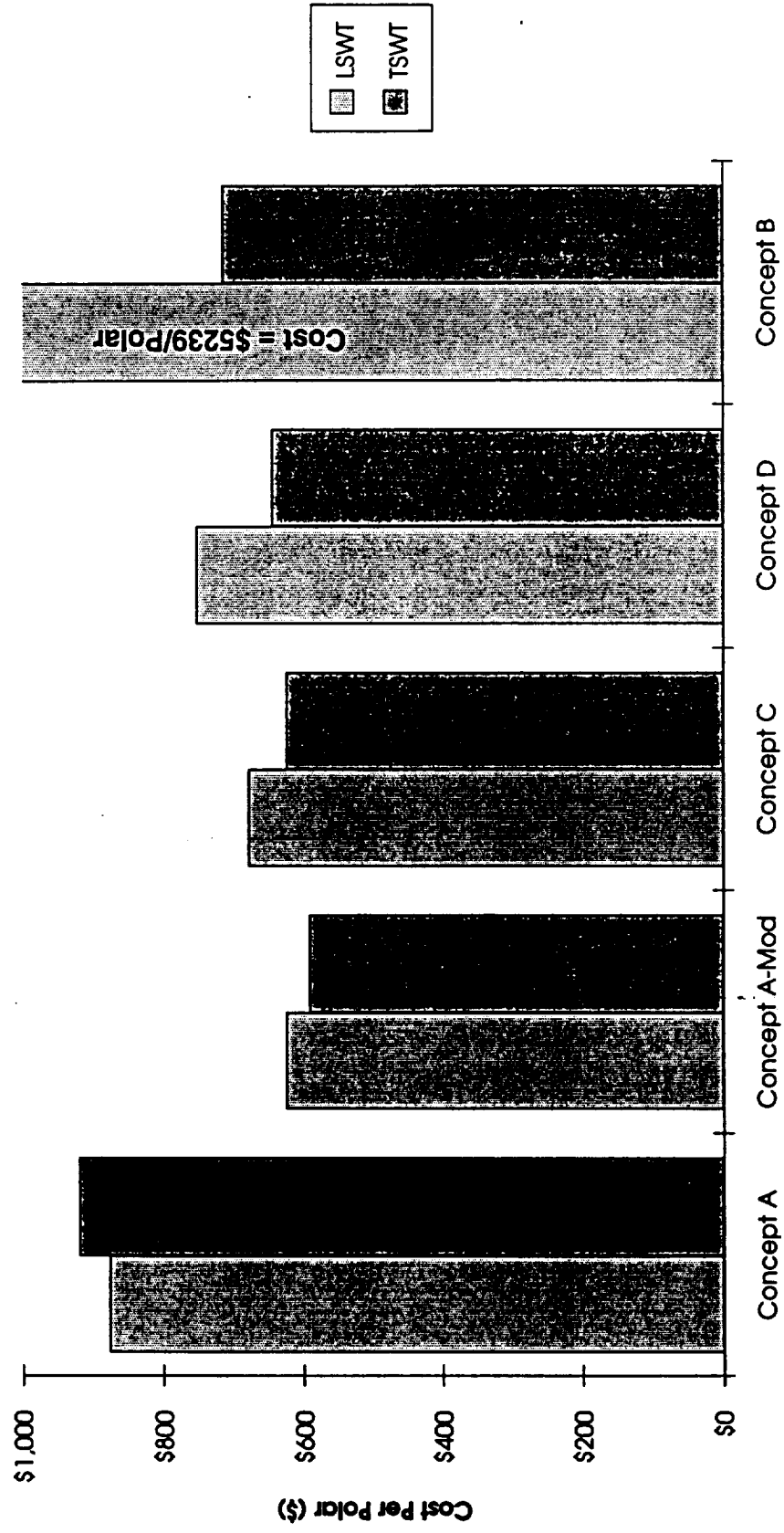
# NATIONAL WIND TUNNEL COMPLEX

Figure 1: Comparison of Concept Annual Operating Costs



# NATIONAL WIND TUNNEL COMPLEX

Figure 2: Comparison of Cost per Polar



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**ALTERNATIVE CONCEPTS**  
**LIFE CYCLE COST COMPARISONS**

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## **NATIONAL WIND TUNNEL COMPLEX**

### **Alternative Concepts Life Cycle Cost Comparison**

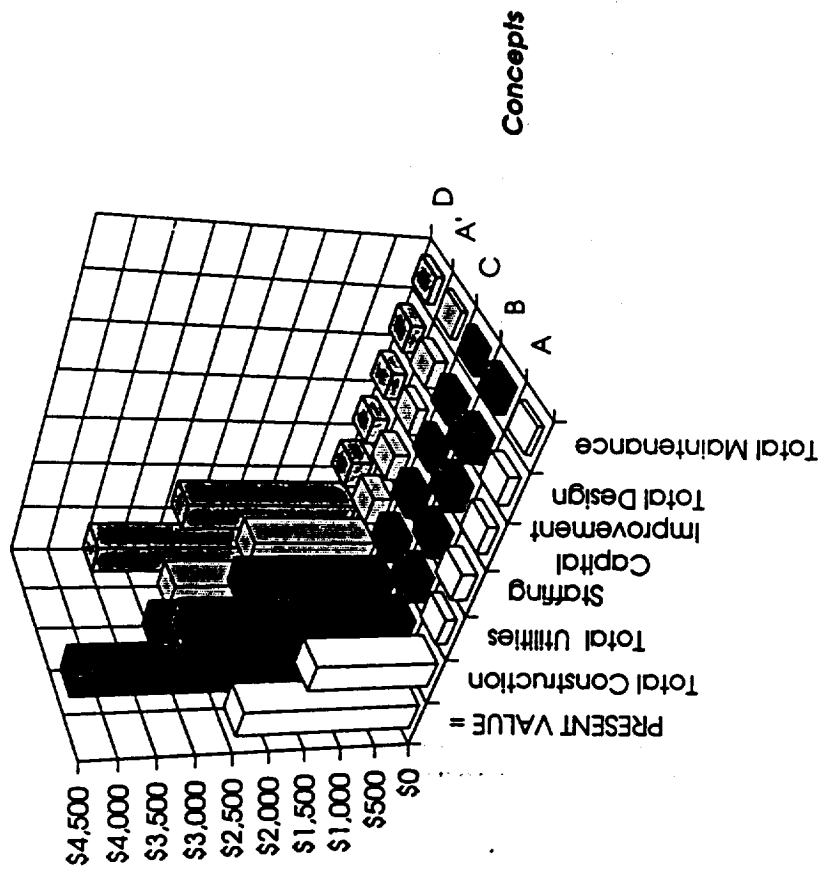
The life cycle cost assessments were performed in the same manner as for the Cost Baseline Life Cycle Cost Assessment. Therefore, only the results of the assessments are provided here. Table 1 and Figure 1 depict the comparative life cycle costs for the alternative concepts for a 30 year facility lifetime. Table 2 and Figure 2 depict the comparative life cycle costs for the alternative concepts for a 40 year facility lifetime. Table 3 and Figure 3 depict the comparative life cycle costs for the alternative concepts for a 50 year facility lifetime.

**Table 1: 30 Year Life - Alternative Concepts Life Cycle Costs Comparisons**  
*(All Costs in \$M)*

	CONCEPT A	CONCEPT A MODIFIED	CONCEPT B	CONCEPT C	CONCEPT D
Total Design	\$165	\$196	\$304	\$198	\$248
Design	\$128	\$159	\$266	\$172	\$211
Studies	\$37	\$37	\$39	\$26	\$37
Total Construction	\$1,749	\$2,012	\$3,219	\$2,187	\$2,641
Total Operations	\$568	\$745	\$941	\$768	\$846
Staffing	\$214	\$233	\$233	\$233	\$233
Total Maintenance	\$83	\$96	\$154	\$104	\$126
Labor	\$40	\$46	\$74	\$50	\$60
Materials	\$14	\$16	\$25	\$17	\$20
Contracts	\$30	\$34	\$55	\$37	\$45
Capital Improvement	\$145	\$167	\$267	\$181	\$219
Total Utilities	\$125	\$249	\$287	\$249	\$268
Electricity	\$109	\$216	\$252	\$216	\$234
Gas	\$4	\$7	\$7	\$7	\$7
Water	\$13	\$26	\$28	\$26	\$27
<b>PRESENT VALUE =</b>	<b>\$2,482</b>	<b>\$2,953</b>	<b>\$4,464</b>	<b>\$3,153</b>	<b>\$3,734</b>

# LIFE CYCLE COST SUMMARY

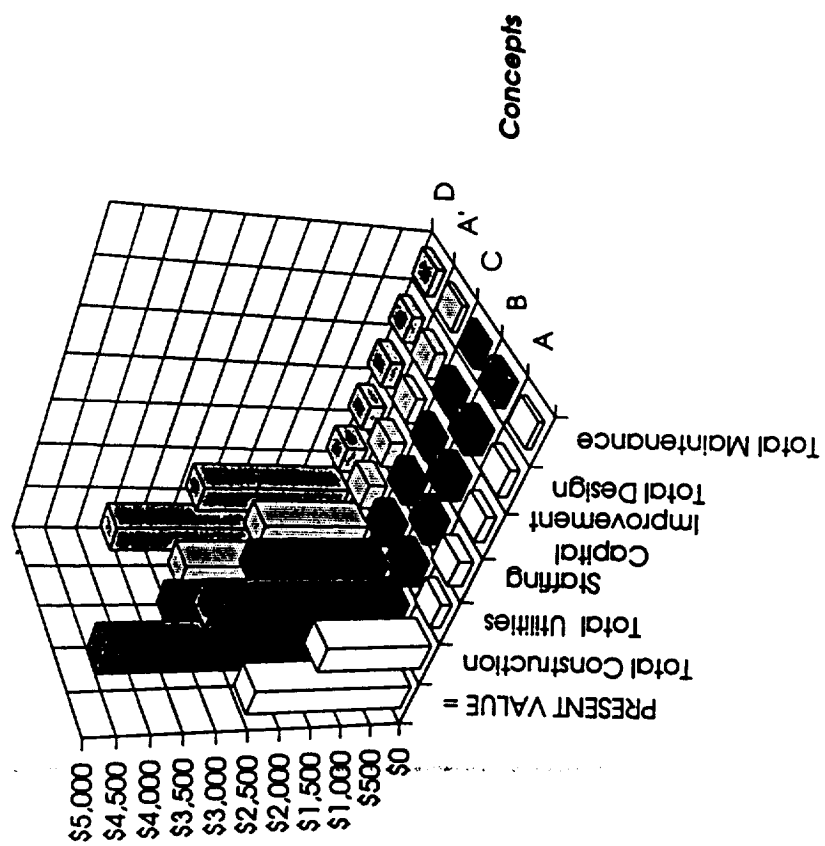
Figure 1: 30 Year Life



**Table 2: 40 Year Life - Alternative Concepts Life Cycle Costs Comparisons**  
(All Costs in \$M)

	CONCEPT A	CONCEPT A-MODIFIED	CONCEPT B	CONCEPT C	CONCEPT D
Total Design	\$165	\$196	\$304	\$198	\$248
Design	\$128	\$159	\$266	\$172	\$211
Studies	\$37	\$37	\$39	\$26	\$37
Total Construction	\$1,749	\$2,012	\$3,219	\$2,187	\$2,641
Total Operations	\$642	\$842	\$1,063	\$867	\$955
Staffing	\$242	\$263	\$263	\$263	\$263
Total Maintenance	\$94	\$108	\$174	\$118	\$142
Labor	\$45	\$52	\$83	\$56	\$68
Materials	\$15	\$18	\$28	\$19	\$23
Contracts	\$34	\$39	\$62	\$42	\$51
Capital Improvement	\$164	\$188	\$301	\$205	\$247
Total Utilities	\$141	\$281	\$324	\$281	\$303
Electricity	\$123	\$244	\$285	\$244	\$264
Gas	\$4	\$8	\$8	\$8	\$8
Water	\$14	\$29	\$31	\$29	\$30
<b>PRESENT VALUE =</b>	<b>\$2,556</b>	<b>\$3,049</b>	<b>\$4,586</b>	<b>\$3,252</b>	<b>\$3,844</b>

### Figure 2: 40 Year Life

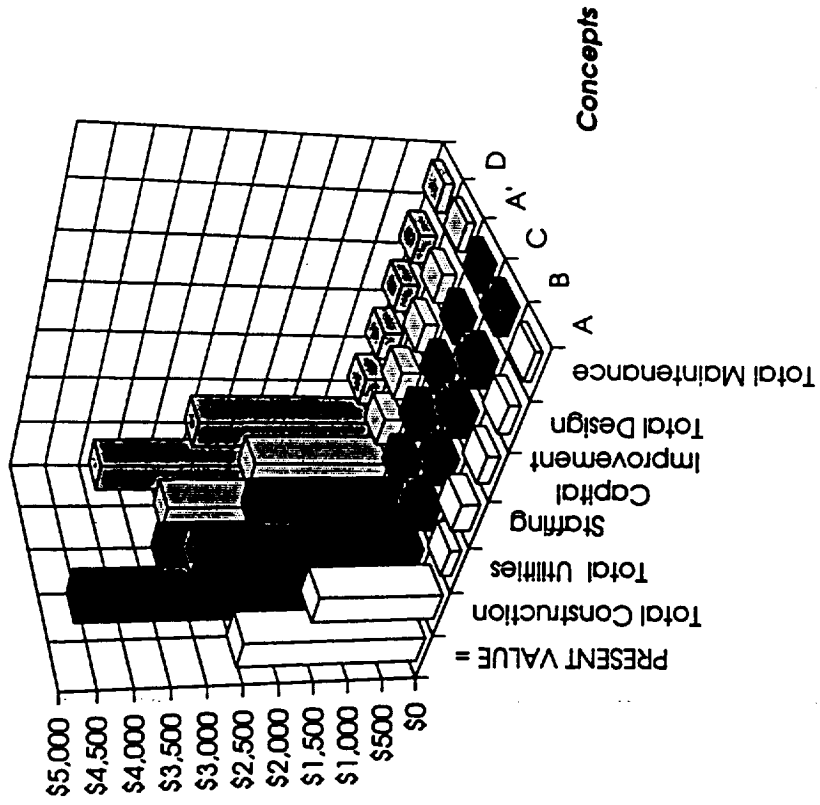


**Table 3: 50 Year Life - Alternative Concepts Life Cycle Costs Comparisons**  
*(All Costs in \$M)*

	CONCEPT A	CONCEPT A MODIFIED	CONCEPT B	CONCEPT C	CONCEPT D
Total Design	\$165	\$196	\$304	\$198	\$248
Design	\$128	\$159	\$266	\$172	\$211
Studies	\$37	\$37	\$39	\$26	\$37
Total Construction	\$1,749	\$2,012	\$3,219	\$2,187	\$2,641
Total Operations	\$689	\$903	\$1,141	\$931	\$1,026
Staffing	\$260	\$283	\$283	\$283	\$283
Total Maintenance	\$101	\$116	\$186	\$127	\$153
Labor	\$48	\$56	\$89	\$61	\$73
Materials	\$16	\$19	\$30	\$21	\$25
Contracts	\$36	\$42	\$67	\$45	\$55
Capital Improvement	\$176	\$202	\$324	\$220	\$266
Total Utilities	\$152	\$302	\$348	\$302	\$325
Electricity	\$132	\$263	\$306	\$263	\$284
Gas	\$5	\$8	\$9	\$8	\$8
Water	\$15	\$31	\$33	\$31	\$32
<b>PRESENT VALUE =</b>	<b>\$2,603</b>	<b>\$3,111</b>	<b>\$4,664</b>	<b>\$3,316</b>	<b>\$3,914</b>

# LIFE CYCLE COST SUMMARY

Figure 3: 50 Year Life



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**ATTACHMENT 4**

**NATIONAL WIND TUNNEL COMPLEX**

**INDEPENDENT ASSESSMENTS**

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3

## **NATIONAL WIND TUNNEL COMPLEX**

### **Independent Assessments**

The NWTC costs were reviewed by two different organizations. The Fluidyne Engineering Corporation was contracted to provide a cost assessment of Concept A. The assessment was to leverage from the original Boeing Wind Tunnel efforts. The FSO developed an independent cost estimate for Concept A. FSO and Fluidyne and Bechtel personnel compared their estimates. Adjustments to the estimates were made to account for discoveries made, information omitted or to resolve differences. Some differences remained after the review period. The final review results comparison between FSO and Fluidyne is provided in Table 1.

The second review was conducted by an Ad-Hoc review team from NASA Headquarters. The review considered Concepts A, A-Modified, and D. The review panel worked with the FSO personnel for a period of approximately 2 weeks. The review was an intense activity that scrutinized all aspects of the project from the technical and cost assessments through the schedule, acquisition strategies, and operating scenarios. The Ad-Hoc review panel had a contract with Sverdrup Technologies to provide the technical and cost expertise for the assessments of the FSO efforts. The results of the independent Sverdrup estimates were reviewed by FSO personnel. As with the Fluidyne review activity, the estimates were reviewed jointly (both the FSO and Sverdrup estimates). Discoveries made, errors, etc. were incorporated into revised estimates. The results of the comparison are provided in Table 2 for Concept A (FSO, Sverdrup and Fluidyne), and Table 3 for Concept D.

The Ad-Hoc review team was to provide an independent review and assessment of the concepts, the requirements, the technical approaches, project cost, project schedule, management approach, and the list of required areas of study (technical risk). The Ad-Hoc review team was to report the findings to the FSO and to NASA Headquarters, and to make recommendations.

A top level summary of the Ad-Hoc Review Findings is:

1. The maturity of the project is extremely low.
2. The performance requirements are changing. Therefore, engineering requirements are not defined or documented.
3. The design is very complex, and is currently in the early conceptual stage of development.
4. No major errors or omissions were found in the FSO cost estimates.
5. The low maturity of the complex design is reflected in the high cost allocation to risk.
6. The 10-year schedule use by FSO was only for cost estimating.

7. The low level of the schedule maturity is not reflected in the cost estimate.
8. Accelerated schedule holds potential for significant cost savings.
9. No general plan for implementing the new wind tunnels has been developed.
10. The lack of site selection has been a barrier to developing an implementation plan.

A top level summary of the Ad-Hoc Review Team Recommendations is:

1. **Project Implementation:**
  - Move aggressively to establish the project office and in integrated implementation plan by January 1, 1994.
  - Select project manager by October 1, 1993
  - FSO should coordinate the critical studies before the establishment of the project office
2. **Requirements:**
  - Freeze the major tunnel parameters by August 19, 1993
  - Establish user requirements group by September 1, 1993
  - Resolve critical requirements driving risk or cost by January 1, 1994
3. **Design:**
  - Expedite activities required to award A/E contract before April 1, 1994
  - Conceptual design needs to mature before submitting budget.
4. **Cost:**
  - Determine construction budget by August 1, 1994
  - Establish uniform, consistent, cost estimating methodology
5. **Schedule:**
  - Focus immediate attention on developing a mature schedule and identifying approaches to shorten the critical path.

The Report of Ad-Hoc Team Review of Aeronautics Facilities view graph slides from the Introduction and Top Level Summary sections are provided with this attachment. The entire presentation is available in the FSO files if it is required.

**Table 1: Concept A Cost Estimate Comparison  
Fluidyne and FSO - as of June 21, 1993**  
(All Costs in \$K)

Work Breakdown Structure		Fluidyne	FSO	Comments
1000	Site and Infrastructure	54,220	56,021	Unresolved error in compressor, piping and storage vessels
2000	Buildings	74,606	67,420	
3000	Auxiliary Process Systems	59,975	137,791	
4000	Low Speed Wind Tunnel	185,895	211,273	
5000	Transonic Speed Wind Tunnel	244,353	249,777	
7000	Operations (LSWT and TSWT)	97,430	88,546	
8000	Management and Support	176,293	172,166	
	Engineering Estimate	892,772	982,994	
Risk		125,178	234,972	
	Subtotal	1,017,950	1,217,966	
Taxes		61,077		
Profit		53,951	121,797	
Bond (1%)		11,330	13,398	
Escalation (7 years at 3.5%)		308,963	365,353	
Contingency (10%)		145,327	171,851	
SIES		159,860	189,037	
	Total Construction Cost	1,758,458	2,079,402	
PER		10,000	41,588	
Government PM		84,165	103,719	
Studies		10,000	38,523	
Design		115,031	89,528	
	Budget	1,977,654	2,352,760	

**Table 2: Concept A Cost Estimate Comparison  
Sverdrup and FSO - as of August 3, 1993  
(All Costs in \$K)**

<b>Work Breakdown Structure</b>		<b>Sverdrup</b>	<b>FSO</b>	<b>Fluidyne (6/21/93)</b>
1000	Site and Infrastructure	57,089	56,354	54,220
2000	Buildings	65,993	79,297	74,606
3000	Auxiliary Process Systems	91,879	108,642	59,975
4000	Low Speed Wind Tunnel	187,538	227,286	185,895
5000	Transonic Speed Wind Tunnel	254,792	262,116	244,353
7000	Operations (LSWT and TSWT)	76,292	82,279	97,430
8000	Management and Support	168,723	186,660	176,293
	<b>Engineering Estimate</b>	<b>902,306</b>	<b>1,002,635</b>	<b>892,772</b>
Risk		207,805	216,899	125,178
	<b>Subtotal</b>	<b>1,110,111</b>	<b>1,219,534</b>	<b>1,017,950</b>
Taxes				61,077
Profit		72,157	121,953	53,951
Bond (1%)		9,458	13,415	11,330
Escalation (7 years at 3.5%)		321,766	365,824	308,963
Contingency (10%)		151,349	172,073	145,327
SIES		112,906	151,424	159,860
	<b>Total Construction Cost</b>	<b>1,777,747</b>	<b>2,044,222</b>	<b>1,758,458</b>
PER		17,777	40,884	10,000
Government PM		88,887	102,961	84,165
Studies		21,233	38,523	10,000
Design		66,287	89,592	115,031
	<b>Budget</b>	<b>1,971,932</b>	<b>2,316,183</b>	<b>1,977,654</b>

**Table 3: Concept D Cost Estimate Comparison  
Sverdrup and FSO - as of August 3, 1993**  
(All Costs in \$K)

<b>Work Breakdown Structure</b>		<b>Sverdrup</b>	<b>FSO</b>	<b>Differences</b>
1000	Site and Infrastructure	65,780	59,739	Substation estimation difference
2000	Buildings	116,362	102,452	Scaling methodology from Concept A-Mod to Concept D
3000	Auxiliary Process Systems	149,425	156,973	Burden rate estimating methods
4000	Low Speed Wind Tunnel	348,115	473,777	Material unit cost/quantity and activation/calibration scope
5000	Transonic Speed Wind Tunnel	298,548	341,207	Test plenum/carts estimate and activation/calibration scope
7000	Operations (LSWT and TSWT)	97,418	106,479	Instrumentation estimate methods
8000	Management and Support	201,818	200,611	
	<b>Engineering Estimate</b>	<b>1,277,466</b>	<b>1,441,238</b>	
	<b>Subtotal</b>	<b>333,089</b>	<b>350,254</b>	
Risk		<b>1,610,555</b>	<b>1,791,492</b>	
Profit		104,686	179,149	FSO used 10%; Sverdrup used 7%; both assumed two tiers
Bond (1%)		13,722	19,706	FSO used 1%; Sverdrup used 0.8%
Escalation (7 years at 3.5%)		466,820	537,394	Same factor different base
Contingency (10%)		219,578	252,774	Same factor different base
SIES		154,576	222,441	FSO used 8%; Sverdrup used 6%
	<b>Total Construction Cost</b>	<b>2,569,937</b>	<b>3,002,956</b>	
PER		25,699	60,059	FSO used 2%; Sverdrup used 1%
Government PM		141,347	158,762	Same factor different base
Studies		22,668	38,523	Different Scopes
Design		101,423	123,168	Different assumptions on level of design maturity and design complexity
	<b>Budget</b>	<b>2,861,047</b>	<b>3,384,168</b>	

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**FACILITIES COSTING AND ENGINEERING**

**INDEPENDENT REVIEW  
OF  
AERONAUTICS R & D FACILITIES PROJECTS**

***National Facility Study  
Facilities Costing and Engineering Task Group  
NASA Headquarters Code JX  
August 1993***

**FACILITIES COSTING AND ENGINEERING**

**REPORT  
OF  
AD-HOC TEAM REVIEW  
OF  
AERONAUTICS FACILITIES**

**WILLIAM C. STAMPER  
AUGUST 6, 1993**

## **FACILITIES COSTING AND ENGINEERING**

### **OUTLINE**

- **Purpose**
- **Functions and Responsibilities**
- **Team Composition**
- **Chronology and Review Approach**
- **Facility Concepts**
- **Work Breakdown Structure**
- **Top-level Summary**
- **Technical Assessments/Issues**
- **Cost Analysis Summary**
- **Recommendations**

# **FACILITIES COSTING AND ENGINEERING**

## **CONTENTS**

### **Report**

AH 1 - AH 33

### **Appendix:**

#### **Functional Requirements Working Group Issues**

FR 1 - FR 36

#### **Acquisition/Schedule Working Group Issues**

A/S 1 - AS 27

#### **Engineering Working Group Issues**

E 1 - E 17

#### **Cost Estimating Working Group Issues**

CE 1 - CE 26

#### **Propulsion Issues (all working groups)**

P 1 - P 7

### **Review Cost Estimates:**

#### **Concept A**

A 1 - A 8

#### **Concept A Modified**

AM 1 - AM 8

#### **Concept D**

D 1 - D 8

## **FACILITIES COSTING AND ENGINEERING**

### **PURPOSE OF REVIEW**

- Independent review and assessment of the Low Speed Wind Tunnel (LSWT) and the Transonic Speed Wind Tunnel (TSWT)
  - Concepts/technical issues
  - Cost
  - Schedule
  - Required studies
- Preliminary Review of other aeronautics R&D FY 1995 new starts

## **FACILITIES COSTING AND ENGINEERING**

### **FUNCTIONS AND RESPONSIBILITIES**

- Establish common ground rules for costing and schedules
  - Design, construction, consolidation, maintenance, and disposition
  - Consistent methodology between NASA and DOD
- Provide facilities engineering technical support
  - Acquisition and execution strategies
  - Verification of infrastructure needs
- Independent review and analysis of preliminary cost estimates and schedules - (Non-Advocate)
- Participate in and support site selection studies

## **FACILITIES COSTING AND ENGINEERING**

### **TEAM COMPOSITION**

Bill Stamper (chairman)	NASA Headquarters/Facilities Engineering
Bill Stein (Co-chair)	Corps of Engineers, South Atlantic Division
Dave Engelbert	Ames Research Center/Systems Engineering Division
Dan Bufton	Ames Research Center/Systems Engineering Division
Dan Petroff	Ames Research Center/Aerodynamics Division
LTC Guy Demoret	Arnold Engineering Development Center/J-6 Project
Norm Scaggs	Wright Laboratories/Flight Dynamics Directorate
Ed Slana	NASA Headquarters/Facilities Engineering
Rich Wickman	NASA Headquarters/Facilities Engineering
Delano Wilson	NASA Headquarters/Office of the Comptroller
Mike Green	NASA Headquarters/Office of Aeronautics
Suey Yee	NASA Headquarters/Office of Aeronautics
Frank Steinle	NASA Headquarters/Office of Aeronautics
Jim Osborn	Langley Research Center/Facilities Engineering
Jack Hummel	Corps of Engineers, South Atlantic Division
Larry Durden	Corps of Engineers, Mobile District (J-6 Project)
Bill Griffin	Corps of Engineers, Mobile District
Dan Payne	Corps of Engineers, Mobile District

## **FACILITIES COSTING AND ENGINEERING**

### **WORKING GROUPS**

#### **FUNCTIONAL REQUIREMENTS**

Frank Steinle  
Norm Scaggs  
Guy Demoret  
Dan Petroff

#### **ENGINEERING**

Dave Engelbert  
Jim Osborn  
Bill Stein  
Suey Yee

#### **COST ESTIMATING/LIFE CYCLE**

Delano Wilson  
Dan Bufton  
Jack Hummel  
Bill Griffin  
Rich Wickman  
Mike Green

#### **ACQUISITION/SCHEDULE**

Larry Durden  
Dan Payne  
Ed Slana

## **FACILITIES COSTING AND ENGINEERING**

### **CHRONOLOGY**

- JX made early decision to use A&E support
  - Sverdrup was tasked through Langley contract
- Review team received a briefing on preliminary requirements from Aero Working Group 4/28/93
- After Facility Study Office (FSO) was formed in May 1993, JX and FSO met and agreed on review schedule and FSO deliverables
- FSO delivered Concept A, A Modified, B, and C estimates on July 2 and 6
  - Estimates were much higher than expected
  - Aeronautics Task Group met on July 13 & 14 and developed an alternative (Concept D) to achieve maximum performance at lower cost than Concept B
  - Concept D estimate completed by FSO on July 23, 1993
- Sverdrup tasked June 30 to assess FSO concept estimates
- On July 16, Sverdrup redirected to cease assessment of Concepts B and C and add Concept D
- Ad-Hoc Committee expanded to gain more expertise in costing, acquisition planning, and scheduling

## **FACILITIES COSTING AND ENGINEERING**

### **Review Approach**

- Review held at Langley July 26 through August 6, 1993
- In-Briefed by FSO and Sverdrup
- Separated review team into working groups
  - Groups generally paralleled FSO organization
- Review team met daily to analyze findings and progress
- Working groups reviewed elements of project and coordinated directly with counterparts in FSO
- Working groups participated in FSO - Sverdrup review and adjustment of respective cost estimates
- Ad Hoc Team briefed FSO on findings and recommendations at end of review
- Aeronautics R & D Task Group briefed on findings and recommendations Aug 18

# FACILITIES COSTING AND ENGINEERING

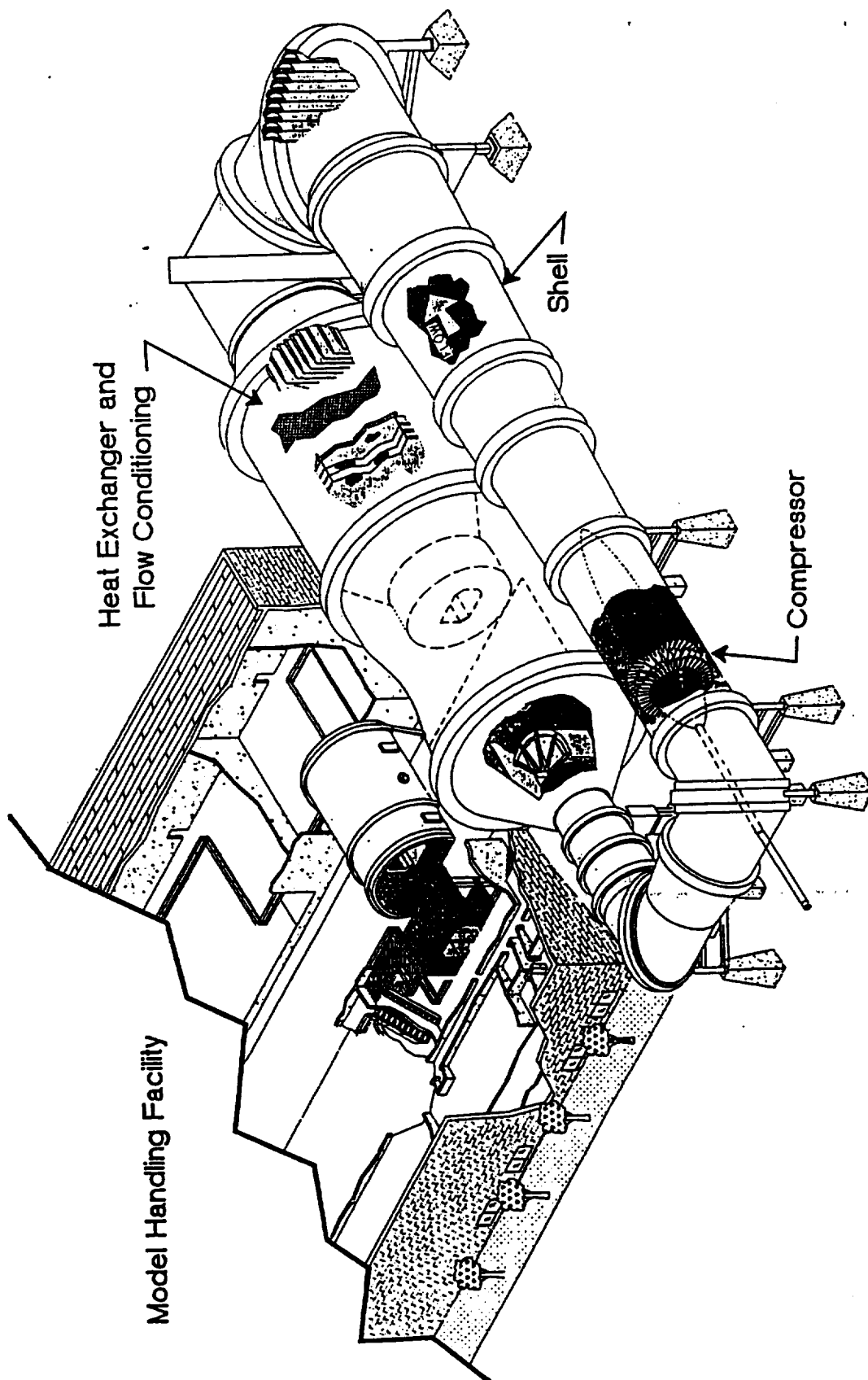
## LOW SPEED

## WIND TUNNEL REQUIREMENTS

### Operation of National Wind Tunnels

Parameter	Concept A	Concept A Modified	Concept D
<b>Max Rey No</b>	16.6 Million	16.6. Million	~ 20 Million
• Mach Range	0.05 to 0.60	0.05 to 0.60	0.05 to 0.60
• Chord Length	1.79 ft	1.79 ft	~ 2.2 ft
• Ops Press	0.07 to 5 atm	0.07 to 5 atm	0.07 to 5 atm
• Test Section	16x20 ft - 288 ft <sup>2</sup>	16x20 ft - 288 ft <sup>2</sup>	20x24 ft - 480 ft <sup>2</sup>
• Fillets	Yes	Yes	No
• Temp	Ambient + 30°F	Ambient + 30°F	Ambient + 30°F
• Test Gas	Air	Air	Air
• Drive Power	M = 0.3 @ 5 atm; open jet	M = 0.3 @ 5 atm & 110°F	M = 0.3 @ 5 atm & 110°F
<b>Productivity</b>			
• Carts	3 Polars/OH 2 (1 sting & 1 floor)	5 Polars/OH 3 (1 sting & 2 floor) 35 ft open jet	5 Polars/OH 3 (1 sting & 2 floor) (*) ft open jet
• Press Rate	5 atm in 50 min	5 atm in 50 min	5 atm in 50 min
<b>Flow Quality</b>			
• Temp Distr	± 1.5°F	± 1.0 °F	± 1.0 °F
• Turbulence, %	0.08	.04 long, .08 vert, lat	.04 long, .08 vert, lat
• Noise	50.6 db	59.4 db	59.4 db
• Stream angle gradient	± 0.1°	< ± 0.1°	< ± 0.1°F
• Static press	0.12° (2σ)	0.01°/ft	0.01°/ft
• Dyn press	0.25%q	± 0.1%	± 0.1%

• Open jet length scaled consistent with 35 ft for A Modified



## Low Speed Wind Tunnel

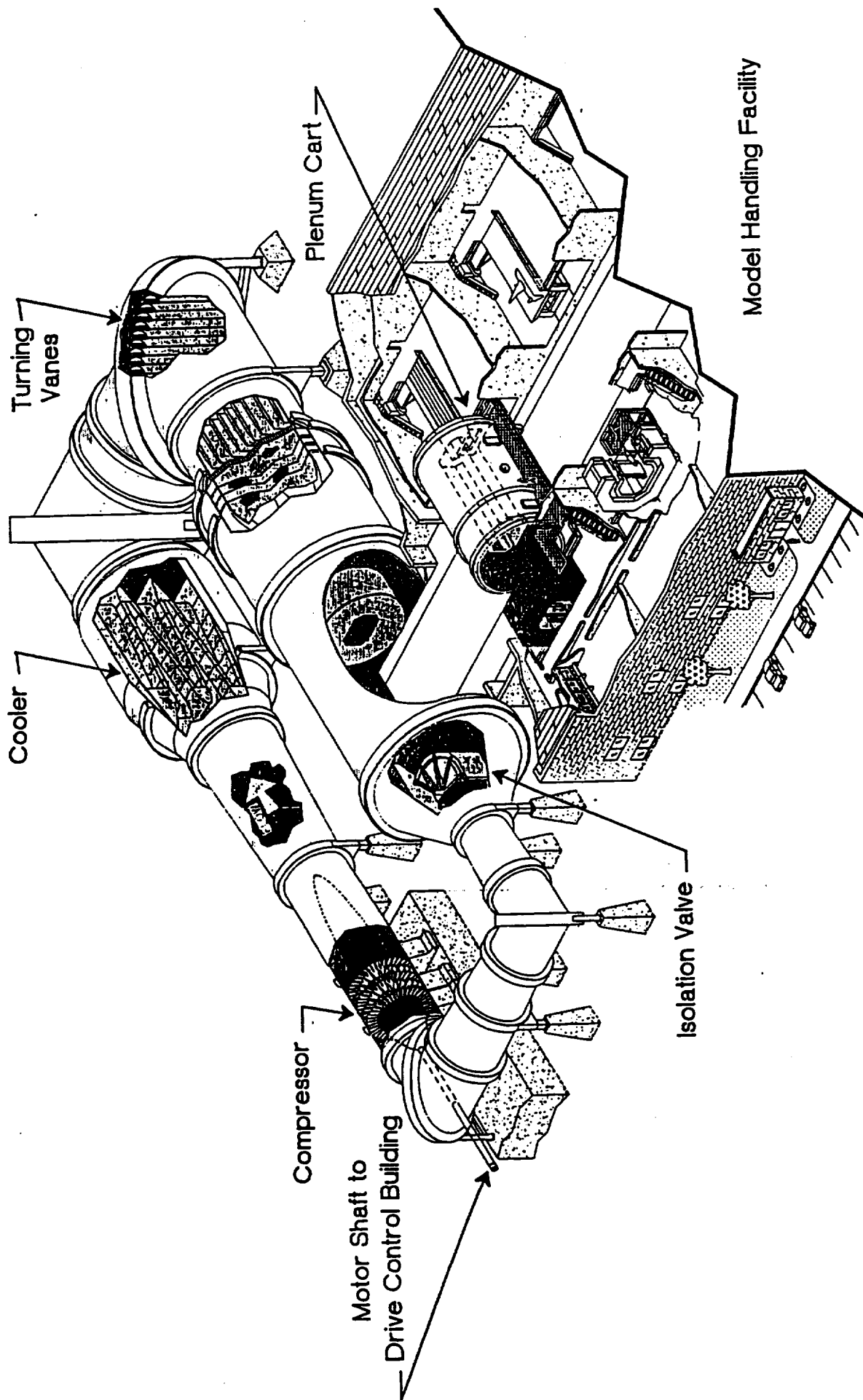
# FACILITIES COSTING AND ENGINEERING

## TRANSONIC

## WIND TUNNEL REQUIREMENTS

### Operation of National Wind Tunnels

Parameter	Concept A	Concept A Modified	Concept D
<b>Max Rey No</b>	<b>27 Million</b>	<b>29 Million</b>	<b>29 Million</b>
• Mach Range	0.1 to 1.3 Fixed Noz	0.05 to 1.3 Fixed Noz	0.05 to 1.5 Flex Noz
• Chord Length	1.31 ft	1.31 ft	1.31 ft
• Ops Press	0.07 to 5 atm	0.07 to 5 atm	0.07 to 5 atm
• Test Section	11x15.5 ft – 158 ft <sup>2</sup>	11x15.5 ft – 158 ft <sup>2</sup>	11x15.5 ft – 158 ft <sup>2</sup>
• Fillets	Yes	Yes	No
• Temp	Ambient + 30°F	Ambient + 30°F	Ambient + 30°F
• Test Gas	Air	Air	Air
• Drive Power	M = 0.95 @ 5 atm	M = 1.0 @ 5 atm & 100°F	M = 1.0 @ 5 atm & 100°F
<b>Productivity</b>			
• Carts	10 Polars/DH	8 Polars/OH	8 Polars/OH
• Press Rate	2 (1 sting & 1 floor) 5 atm in 50 min	3 (2 sting & 1 floor) 5 atm in 50 min	3 (2 sting & 1 floor) 5 atm in 50 min
<b>Flow Quality</b>			
• Temp Distr	± 1.5°F	± 1.0°F	Equal to or better than AMES 11ft tunnel
• Turbulence, %	0.15	0.15	
• Noise	10-30 db > Boeing's	95 db	
• Stream angle gradient	0.1° subsonic	0.1°	
• Static press	0.15° (2σ) subsonic	0.01°/ft	
• Dyn press	0.0015° (2σ) subsonic	0.001°	



## Transonic Wind Tunnel

## **FACILITIES COSTING AND ENGINEERING**

### **WORK BREAKDOWN STRUCTURE (WBS) ORGANIZATION**

**FIRST TIER: Total Estimate**

**SECOND TIER: 1000 Site and Infrastructure**

**2000 Buildings**

**3000 Auxiliary Process Systems**

**4000 Low Speed wind Tunnel**

**5000 Transonic Wind Tunnel**

**6000 Supersonic Wind Tunnel**

**7000 Operations**

**8000 Management and Support**

# FACILITIES COSTING AND ENGINEERING

## WORK BREAKDOWN STRUCTURE (WBS) ORGANIZATION

### 3RD TIER

- 5100 TSWT ACOUSTIC ENCLOSURE
- 5200 TSWT PRESSURE SHELL
- 5300 PRESSURE ISOLATION SYSTEM
- 5400 FLOW INTERNALS
- 5500 TEST SECTIONS & PLENUM
- 5600 TEST SUPPORT EQUIPMENT
- 5700 COMPRESSOR & DRIVE SYSTEM
- 5800 ELECT, CONTROLS, & DATA ACQ

### 4TH TIER

- 5510 TEST SECTION COMPONENTS
- 5520 MOVEABLE PLENUM
- 5530 OBSERVATION SYSTEM
- 5540 SHUTTLE CAR

### 5TH TIER

- 5511 US CEILING & WALLS
- 5512 US SLOTTED FLOOR
- 5513 US EXT BALANCE FLOOR
- 5514 DS STING SUPPORT SECT.
- 5515 DS DUMMY STING SECT.

## **TOP LEVEL SUMMARY**

## **FACILITIES COSTING AND ENGINEERING**

### **TOP LEVEL SUMMARY**

- **The Facility Study Office (FSO) has performed in a truly outstanding manner**
  - **Excellent leadership**
  - **Highly talented, motivated staff**
  - **High levels of teamwork and enthusiasm**
  - **Extremely cooperative and candid with the Ad-Hoc Review Team**

## **FACILITIES COSTING AND ENGINEERING**

### **TOP LEVEL SUMMARY**

- **OVERALL PROJECT IS EXTREMELY IMMATURE**
  - Requirements
    - Performance requirements are changing
    - Engineering requirements are not defined or documented
  - Size of components and speed of operations introduce complexity
    - Design is in early conceptual stage of development
  - High cost being driven by productivity requirements and size of facilities
    - No major errors/omissions found in FSO's estimate
    - Low maturity of complex design is reflected in high cost allocation to risk
  - Assumed 10-Year schedule is reasonable
    - 10-year schedule used by FSO for cost estimating only
    - Low level of schedule maturity is not reflected in cost estimate
    - Savings can only occur via non-traditional approaches and accelerated up-front work
    - Non-traditional approaches may increase risk

**TOP LEVEL SUMMARY**

- **NO PLAN FOR IMPLEMENTING THE PROJECT HAS BEEN DEVELOPED**
  - Lack of site selection will be a barrier to developing an Implementation Plan
    - Difficult to assemble a project team
    - Most implementation strategies are impacted by the site
  - Cost estimate is impacted by acquisition strategy and implementation approach
- **ABILITY TO ACHIEVE PRODUCTIVITY GOALS IS A CONCERN**
  - Twice the world's best facilities
  - Significant cost driver
  - Components require extremely high reliability
- **WHAT HAS TO BE DONE FOR AN FY 1996 CONSTRUCTION START?**

# **TECHNICAL ASSESSMENTS**

## **FACILITIES COSTING AND ENGINEERING**

### **FUNCTIONAL REQUIREMENTS WORKING GROUP FINDINGS**

- **LEVEL OF DESIGN NEEDS TO BE DETERMINED**
  - Detailed design can cause higher integration cost
  - Performance specification can increase risk
- **HOST INSTALLATION INVOLVEMENT AND SUPPORT IS REQUIRED**
  - Study to identify cost and requirements is needed
- **TEMPEST SHIELDING IN TEST PREP/CONTROL BUILDINGS IS NOT NEEDED**
  - Study security needs of users
- **AUXILIARY PROCESS SYSTEM: AIR HEATERS REQUIRE STUDY-MAY NOT BE NEEDED. AIR STORAGE VOLUME NEEDS TO BE INCREASED**
- **LOW SPEED WIND TUNNEL: MANY STUDIES NEEDED, INCLUDING PERFORMANCE/OPTIMIZATION STUDIES, HEAT EXCHANGER, TEST SECTION CART SLOT CONFIGURATION, AERODYNAMIC MODEL OF COMPRESSOR, SHAPE OF COLLECTOR (OPEN JET TEST SECTION), COMPRESSOR ROTOR HUB/BLADES' ALTERNATIVE ISOLATION VALVES, CUT-OFF FREQUENCY IN ANECHOIC CHAMBER**
- **TRANSONIC SPEED WIND TUNNEL: MANY STUDIES NEEDED INCLUDING PERFORMANCE/OPTIMIZATION STUDIES; OPTIMIZATION STUDIES FOR CONTOURED NOZZLE, CHOKE SYSTEM, TEST SECTION; PILOT TEST FOR FOLDED HEAT EXCHANGER**

## **FACILITIES COSTING AND ENGINEERING**

### **ACQUISITION/SCHEDULE WORKING GROUP FINDINGS**

- **SENSE OF URGENCY MUST BE ATTACHED AT ALL LEVELS**
  - Early decisions can greatly affect cost
- **A DEDICATED PROJECT STAFF MUST BE ESTABLISHED AS SOON AS POSSIBLE**
- **MANAGEMENT PLAN SHOULD BE THE FIRST ORDER OF BUSINESS FOR THE PROJECT OFFICE.**
- **SITE SELECTION IMPACTS MUST BE ADDRESSED**
  - Environmental studies could become "show-stopper"
  - Impacts construction cost and schedule
- **STUDIES MUST BE INITIATED.**
  - Use FSO for oversight and Systems Engineering until Project Office is formed
- **ACQUISITION STUDY IS REQUIRED TO DETERMINE BEST APPROACH**
- **ACTIVATION OF THE PROJECT MUST BE AN INTEGRAL PART OF THE CONSTRUCTION PROCESS**
  - Operator of facility should be involved in development of facility requirements
- **ASSUMED 10-YEAR SCHEDULE IS REASONABLE**
  - Detailed schedule needs to be developed

## **FACILITIES COSTING AND ENGINEERING**

### **ENGINEERING WORKING GROUP FINDINGS**

- **NO GENERAL PLAN EXISTS FOR IMPLEMENTATION**
  - Transition from FSO to Project Office must be made at earliest possible date
  - Cost and schedule are adversely impacted by lack of permanent, adequately staffed, Project Office
- **FURTHER DEVELOPMENT OF CONCEPTUAL DESIGNS IS NEEDED BEFORE SUBMITTING CONSTRUCTION BUDGET**
- **PLAN AND SCHEDULE NEED TO BE ESTABLISHED TO FIRM-UP AND DOCUMENT REQUIREMENTS**
- **CRITICAL REQUIREMENTS DRIVING RISK OR COST SHOULD BE REVIEWED**
  - Productivity
  - Required tolerances for massive isolation valves
  - Transonic ejector system vs. three stage compressor for high-mach numbers
  - Planned large models may be expensive and wall interference effects may be significant
- **STREAMLINED MANAGEMENT SYSTEM MUST BE ESTABLISHED AND BARRIERS MUST BE IDENTIFIED AND ELIMINATED**
- **PER CAN BE ELIMINATED, PROCEED WITH DESIGN ACTIVITY THAT INCORPORATES ESSENTIAL BENEFITS NORMALLY OBTAINED FROM PER**

## **FACILITIES COSTING AND ENGINEERING**

### **ENGINEERING WORKING GROUP FINDINGS (Continued)**

- **PERFORMANCE REQUIREMENTS COULD DRIVE ENGINEERING TO COMPLEX, UNPROVEN SYSTEMS**
  - Robust, simple, reliable hardware is needed to meet productivity goals
- **ALL CRITICAL STUDIES MUST BE IDENTIFIED AND BEGUN**
- **ACQUISITION STRATEGY CAN HAVE A PROFOUND AFFECT ON COST, SCHEDULE, AND OTHER PROJECT ELEMENTS**
  - Initial task of Project Office should be to develop strategy

## **FACILITIES COSTING AND ENGINEERING COST ESTIMATING WORKING GROUP FINDINGS**

- AD HOC REVIEW REVISED ESTIMATE SHOULD BE USED AT THIS TIME
- BASIS FOR TEMPEST REQUIREMENT IS UNCERTAIN AND ELIMINATION OF REQUIREMENT SHOULD BE CONSIDERED
- SITE SELECTION MUST BE MADE AS SOON AS POSSIBLE TO PERMIT DETAILED DESIGN TO PROCEED AND IMPROVE COST ESTIMATE PRECISION
- PROJECT TEAM, MANAGEMENT PLAN, AND IMPLEMENTATION STRATEGY MUST BE DEVELOPED AS SOON AS POSSIBLE
- AREAS OF CONCERN:
  - Impact of site selection not reflected in estimate
  - Costing methodology is appropriate for pre-conceptual design stage. Use of lump sum quantities (i.e. \$ per pound) for complex items carries realistic high risk
  - Consistent wage rates and risk factor and cost methodology must be applied across all elements of WBS
  - Overhead and Profit will vary depending on contracting approach
  - Supervision, Inspection, and Engineering Services (SIES) and Preliminary Engineering Report (PER) costs based on percentage rather than requirements. Estimates need further refinement when implementation strategy is known
  - Spare parts to ensure high reliability and productivity not Included in estimate
- CODE B RECOMMENDS HQ RESERVE LEVEL OF 10% BE ADDED TO COST ESTIMATE

## **COST ANALYSIS SUMMARY**

# FACILITIES COSTING AND ENGINEERING

## Costing and Engineering Cost Estimate - Budget Level (\$B - Year 2000 \$'s)

	Concept A	Concept A (Modified)	Concept D
FSO BASELINE (6/30/93)	2.39 (24%)*	2.75 (25%)	3.60 <sup>1</sup> (26%)
Original Independent A & E Estimate (7/24/93)	1.82 (25%)	2.00 (24%)	2.56 (27%)
Revised Independent A & E Estimate (8/2/93)	1.97 (23%)	2.20 (24%)	2.86 (26%)
Ad Hoc Review Estimate (8/6/93)	2.32 (22%)	2.68 (23%)	3.38 (24%)

# Facilities Costing and Engineering Ad Hoc Review Concept A - Cost Estimates

(Dollars x 10<sup>3</sup>)

	Baseline Engineering Estimates		With Corrections and Additions	
	FSO 6/30/93	Independent A & E Estimate 7/30/93	Ad Hoc Review Estimate 8/6/93	Revised Independent A & E 8/2/93
<b>Work Breakdown Structure</b>				
1000 Site and Infrastructure	55,685	57,089	56,354	57,089
2000 Building	67,420	65,993	79,297	65,993
3000 Auxiliary Process Systems	126,273	92,782	108,642	91,879
4000 Low Speed Wind Tunnel	229,843	170,282	227,286	187,538
5000 Transonic Speed Wind Tunnel	258,733	244,269	262,116	254,792
7000 Operations (LSWT and TSWT)	88,633	73,119	82,279	76,292
8000 Management and Support	173,438	176,409	186,660	168,723
<b>Engineering Estimate</b>	<b>1,000,025</b>	<b>879,943</b>	<b>1,002,635</b>	<b>902,306</b>
	<b>235,277</b>	<b>202,695</b>	<b>216,899</b>	<b>207,805</b>
<b>Subtotal</b>	<b>1,235,302</b>	<b>1,082,638</b>	<b>1,219,534</b>	<b>1,110,111</b>
Profit	123,530	51,289	121,953	72,157
Bond	13,588	8,206	13,415	9,458
Escalation (7 yrs. at 3.5%)	370,553	276,958	365,824	321,766
Contingency (10%)	174,297	136,222	172,073	151,349
SIES	191,727	81,733	151,424	112,906
<b>Total Construction Cost</b>	<b>2,108,997</b>	<b>1,637,046</b>	<b>2,044,222</b>	<b>1,777,747</b>
PER	42,180	9,697	40,884	17,777
Government PM	105,319	105,000	102,961	88,887
Studies	38,523	21,233	38,523	21,233
Design	90,153	50,619	89,592	66,287
<b>Budget</b>	<b>2,385,172</b>	<b>1,823,595</b>	<b>2,316,183</b>	<b>1,971,932</b>

# FACILITIES COSTING AND ENGINEERING

## Facilities Costing and Engineering Ad Hoc Review Concept A-Mod - Cost Estimates (Dollars x 10<sup>3</sup>)

	Baseline Engineering Estimates		With Corrections and Additions	
	FSO 6/30/93	Independent Estimate 7/30/93	Ad Hoc Review Estimate 8/6/93	Revised Independent A & E 8/2/93
<b>Work Breakdown Structure</b>				
1000 Site and Infrastructure	55,620	57,122	56,253	57,122
2000 Building	82,490	88,629	93,621	88,629
3000 Auxiliary Process Systems	129,480	94,069	128,073	93,431
4000 Low Speed Wind Tunnel	258,040	183,297	252,247	201,019
5000 Transonic Speed Wind Tunnel	309,165	267,722	315,253	278,245
7000 Operations (LSWT and TSWT)	105,013	86,585	105,804	93,235
8000 Management and Support	195,829	188,077	191,295	180,166
<b>Engineering Estimate</b>	<b>1,135,637</b>	<b>965,501</b>	<b>1,142,547</b>	<b>991,847</b>
	<b>284,866</b>	<b>227,064</b>	<b>267,024</b>	<b>233,831</b>
<b>Subtotal</b>	<b>1,420,503</b>	<b>1,192,565</b>	<b>1,409,571</b>	<b>1,225,678</b>
Profit	142,050	56,496	140,957	79,663
Bond	15,626	9,039	15,505	10,442
Escalation (7 yrs. at 3.5%)	426,108	305,080	422,829	355,234
Contingency (10%)	200,429	150,054	198,886	167,092
SIES	220,472	90,033	175,020	125,696
<b>Total Construction Cost</b>	<b>2,425,188</b>	<b>1,803,267</b>	<b>2,302,768</b>	<b>1,963,705</b>
PER	48,504	10,748	47,255	19,837
Government PM	121,488	105,000	121,502	121,750
Studies	38,523	21,233	38,523	21,233
Design	115,532	57,994	108,538	76,324
<b>Budget</b>	<b>2,749,235</b>	<b>1,998,242</b>	<b>2,678,586</b>	<b>2,202,648</b>

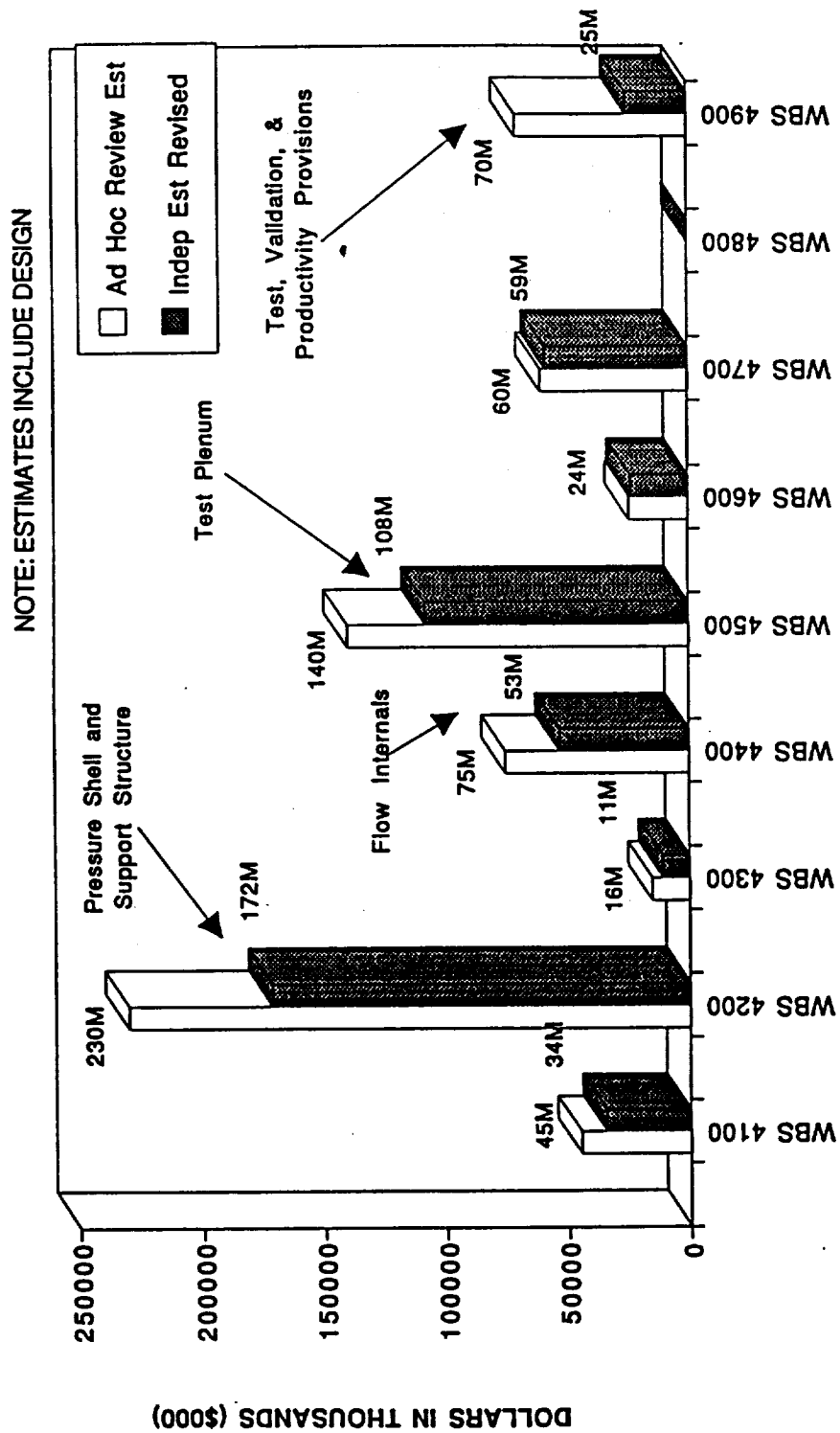
# FACILITIES COSTING AND ENGINEERING

## Facilities Costing and Engineering Ad Hoc Review Concept D - Cost Estimates

(Dollars x 10<sup>3</sup>)

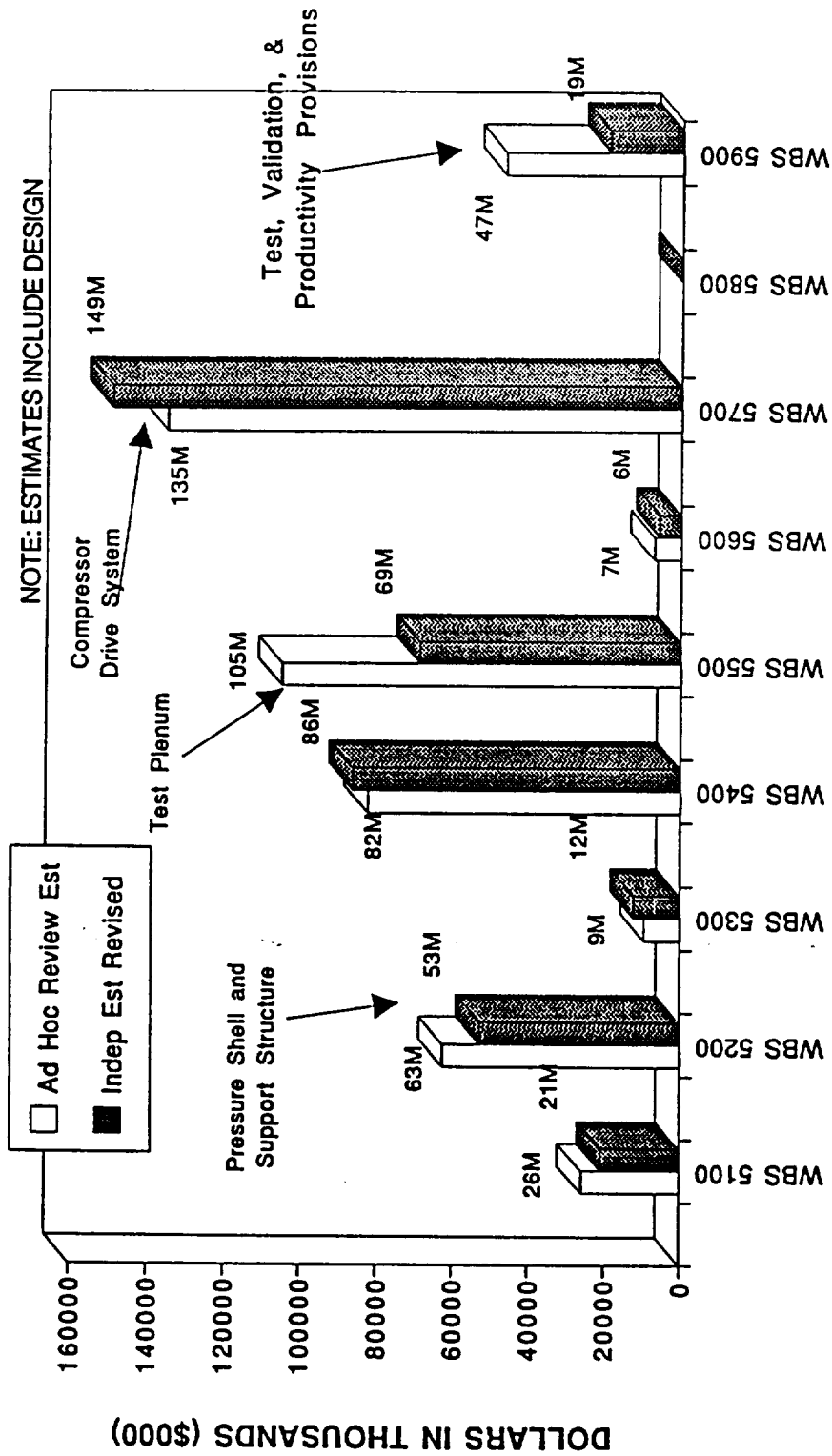
	Baseline Engineering Estimates		With Corrections and Additions	
	FSO 7/23/93	Independent Estimate 7/30/93	Ad Hoc Review Estimate 8/6/93	Revised Independent A & E 8/2/93
<b>Work Breakdown Structure</b>				
1000 Site and Infrastructure	58,626	65,780	59,739	65,780
2000 Building	86,003	116,362	102,452	116,362
3000 Auxiliary Process Systems	187,420	131,898	156,973	149,425
4000 Low Speed Wind Tunnel	485,108	293,073	473,777	348,115
5000 Transonic Speed Wind Tunnel	309,673	293,525	341,207	298,548
7000 Operations (LSWT and TSWT)	113,639	90,855	106,479	97,418
8000 Management and Support	239,228	185,953	200,611	201,818
<b>Engineering Estimate</b>	<b>1,479,697</b>	<b>1,177,446</b>	<b>1,441,238</b>	<b>1,277,466</b>
<b>Risk</b>	<b>383,454</b>	<b>321,361</b>	<b>350,254</b>	<b>333,089</b>
<b>Subtotal</b>	<b>1,863,151</b>	<b>1,498,807</b>	<b>1,791,492</b>	<b>1,610,555</b>
<b>Profit</b>	<b>186,315</b>	<b>74,940</b>	<b>179,149</b>	<b>104,686</b>
<b>Bond</b>	<b>20,495</b>	<b>12,590</b>	<b>19,706</b>	<b>13,722</b>
<b>Escalation (7 yrs. at 3.5%)</b>	<b>558,889</b>	<b>428,311</b>	<b>537,394</b>	<b>466,820</b>
<b>Contingency (10%)</b>	<b>262,885</b>	<b>201,465</b>	<b>252,774</b>	<b>219,578</b>
<b>SIES</b>	<b>289,174</b>	<b>106,776</b>	<b>222,441</b>	<b>154,576</b>
<b>Total Construction Cost</b>	<b>3,180,909</b>	<b>2,322,889</b>	<b>3,002,956</b>	<b>2,569,937</b>
<b>PER</b>	<b>63,618</b>	<b>23,229</b>	<b>60,059</b>	<b>25,699</b>
<b>Government PM</b>	<b>161,196</b>	<b>116,145</b>	<b>158,762</b>	<b>141,347</b>
<b>Studies</b>	<b>38,523</b>	<b>22,668</b>	<b>38,523</b>	<b>22,668</b>
<b>Design</b>	<b>154,680</b>	<b>70,999</b>	<b>123,168</b>	<b>101,423</b>
<b>Budget</b>	<b>3,598,926</b>	<b>2,555,931</b>	<b>3,384,168</b>	<b>2,861,074</b>

# FACILITIES COSTING AND ENGINEERING



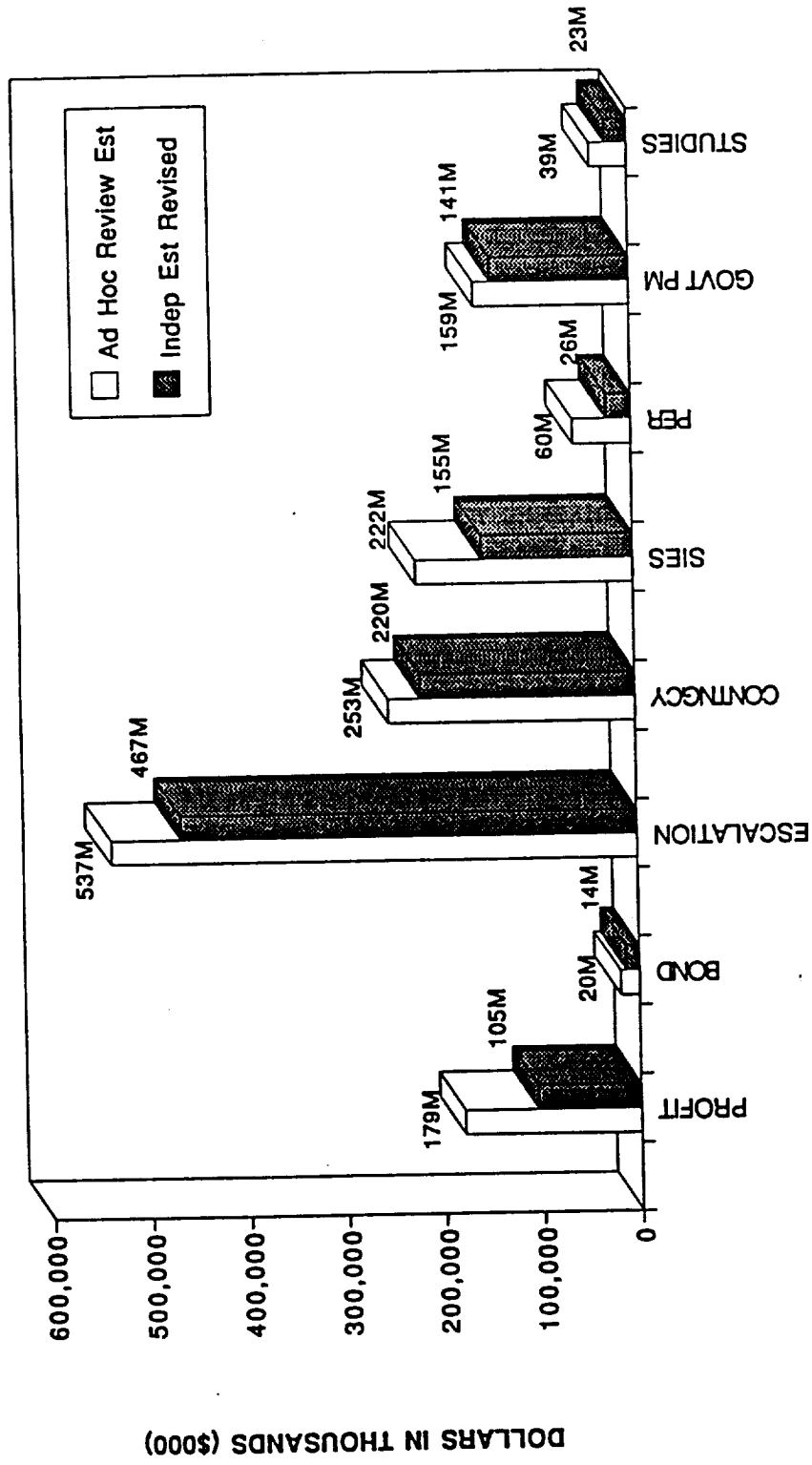
DIFFERENCES IN WBS 4000 ESTIMATES - CONCEPT D

# FACILITIES COSTING AND ENGINEERING



DIFFERENCES IN WBS 5000 ESTIMATES - CONCEPT D

# FACILITIES COSTING AND ENGINEERING



DIFFERENCES IN MARKUPS - CONCEPT D

## **FACILITIES COSTING AND ENGINEERING**

### **SUMMARY RECOMMENDATIONS**

#### **IMMEDIATE ACTIONS ARE REQUIRED TO START CONSTRUCTION IN FY 96**

- **PROJECT IMPLEMENTATION:**

- Select site as soon as possible (not later than January 1, 1994)
- Select Project Manager by October 1, 1993
- Project Manager should focus immediate attention to establish the Project Office and integrated Implementation Plan by January 1, 1994
- FSO should coordinate critical studies before establishment of the Project Office
  - Additional resources are required in FSO

- **REQUIREMENTS**

- Freeze major tunnel parameters by August 19, 1993
- Establish user requirements group by September 1, 1993
- Resolve critical requirements driving risk or cost by January 1, 1994

- **EXPEDITE ACTIVITIES REQUIRED TO AWARD A&E DESIGN CONTRACT BY APRIL 1, 1994**

- **COST**

- Proceed with conceptual studies and design. No new estimating efforts until Project Office is formed at the selected site.
- Establish uniform, consistent estimating methodology
- Refine program budget by August 1, 1994

- **FOCUS IMMEDIATE ATTENTION ON DEVELOPING A MATURE SCHEDULE AND IDENTIFYING APPROACHES TO SHORTEN THE CRITICAL PATH**

## **FACILITIES COSTING AND ENGINEERING**

### **REASONS FOR DIFFERENCES IN COST ESTIMATES**

- **ENGINEERING ESTIMATES**
  - Basic differences of opinion on costing individual items, such as:
    - Degree to which unit price of steel decreases as quantity increases
    - Difference in unit cost of LSWT settling chamber liner
    - Difference in unit price for fabrication of test plenum components
  - Difference in philosophy on systems validation testing (i.e. full I.S.T. versus testing of individual components only)
- **A & E CONSISTENTLY LOWER IN DESIGN**
  - Assumed a less detailed design/more performance specifications
  - Basic difference in philosophy:
    - A & E assumed all engineering requirements would be frozen at start of design
    - FSO assumed some engineering requirements would change as studies mature
- **RISK FACTORS ESSENTIALLY EQUAL, EVEN THOUGH TOTALLY DIFFERENT METHODOLOGIES WERE USED**
- **MARKUPS: IN SOME CASES, A&E MARKUPS WERE SIGNIFICANTLY DIFFERENT. ALL CONCEPTS BEING SIMILAR, THE FOLLOWING ARE THE DIFFERENCES ON CONCEPT D:**
  - A&E Profit (two levels at 3.5% = 7%) does not assume worst case acquisition. FSO Profit (two levels at 5% = 10%) is more conservative (\$74,463,000)
  - A&E SIES (based on estimated level of effort) of 6.4% versus FSO 8% (\$67,866,000)
  - A&E assumes bond at .8% versus 1.0% for FSO (\$5,984,000)
  - A&E assumes PER at 1% versus 2% for FSO (\$34,360,000)

**ATTACHMENT 5**

**NATIONAL WIND TUNNEL COMPLEX**

**CRITERIA AND REQUIREMENTS DOCUMENT**

**FOR**

**CONCEPT D - OPTION 5**



**National Wind Tunnel Complex**

**CRITERIA AND REQUIREMENTS DOCUMENT**

**PRELIMINARY**

**Prepared by**

**Facilities Study Office**

**December, 1993**

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C-4



**Revision Page**

[illegible]

December 9, 1993

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## Introduction

### i. Objectives of the Criteria and Requirements Document

This document defines the top level functional requirements for the National Wind Tunnel Complex (NWTC), and the derived engineering requirements for specific categories and elements. It is intended as a working tool serving as the primary documentation record during the design phases. During the studies, Preliminary Engineering Report (PER), and preliminary design phases, the derived requirements will be updated and expanded to reflect new information. The goal is to conclude the preliminary design phase with a well defined and detailed criteria and requirements package, to be used in completing the design. As the design matures, this information should not constrain the designer(s) from applying good engineering judgment and creative thinking in finding solutions to complex engineering problems.

### ii. Scope of Work and Limitations

The criteria and requirements document is a compilation of baseline criteria, functional requirements, and derived engineering requirements for the NWTC project. It uses a work package breakdown structure to divide the project. It is the controlling source of baseline information for the NWTC design. This document does not contain any information on schedule, cost, test plans, detail design, quality control, or resource requirements. Interface information is of a general nature and used only for Work Breakdown Structure (WBS) definitions. Specific interfaces between work packages are not covered here. The interfaces are provided in the NWTC Project Interface Control Document (to be developed).

### iii. Configuration Management

**Responsibilities:** This Criteria and Requirements document is under configuration control. Changes must be made in accordance with the Project's configuration control procedures. The NWTC Chief Engineer is responsible for the development of this Criteria and Requirements Document and for insuring that the facility, as defined herein, is consistent with NWTC objectives. The Chief Engineer has the overall responsibility for the generation and maintenance of this document. The work package managers have the primary responsibility for maintaining the portion(s) of the document that defines their work package(s). The work package managers shall initiate actions to update this document in a timely manner.

Other project personnel are expected to support the efforts of the work package managers. An accurate and visible baseline must be maintained to assure success. Everyone connected with this project has the responsibility to surface potential changes to the criteria and requirements listed within this document.

Approval of this document and future revisions will be by the NWTC Chief Engineer and the Project Manager.

**Revision Procedure:** Once a revision has been identified, a Request For Change (RFC) form is filled out. If approved, the change is made and the area in the document where the change is

located is denoted with a vertical bar (|) in the right hand margin of the page. The revision sheet is updated and the change is approved by the appropriate personnel. The wording in the description block shall be as specific as possible, giving page numbers where changes have been made. The current Criteria and Requirements Document revision level, and the revision page itself, will reflect the latest approved revisions. Once a change has been approved, the revision sheet and the affected pages will be distributed in accordance with the Distribution List.

#### **iv Document Organization**

The requirements for the NWTC are divided into top level functional requirements and detailed derived requirements. The top level requirements are given under the first and second tier work package numbers. The first and second tier work packages are as follows:

- 1.0 National Wind Tunnel Complex
- 1.1 Site and Infrastructure
- 1.2 Buildings
- 1.3 Auxiliary Process Systems
- 1.4 Low Speed Wind Tunnel
- 1.5 Transonic Speed Wind Tunnel

The derived requirements are presented in the lower tier work package numbers. The derived requirements are organized into three sections: definition, requirement, and criteria.

## 1.0 NATIONAL WIND TUNNEL COMPLEX (NWTC)

**Definition:** The National Wind Tunnel Complex (NWTC) is an integrated test facility. The fundamental objective of the NWTC is to provide wind tunnels that are responsive to customer needs in support of aircraft development. The NWTC will provide highly productive aerodynamic and acoustic test platforms. Fundamental to the NWTC are the precepts of reliability, superior data quality (qualitatively superior to the world's best capabilities), and low cost per data point. The NWTC will provide the capability for aeronautical, engine, and acoustical developmental testing in the subsonic and transonic speed regimes. The NWTC is a stand-alone facility with all support systems including offices, model shops/preparation areas, auxiliary systems, etc. The NWTC includes a pressurized subsonic wind tunnel with a 20-ft by 24-ft test section, a pressurized transonic wind tunnel with an 11-ft by 15.5-ft test section, model buildup and preparation areas, supporting calibration facilities, ancillary supporting facilities, supporting auxiliary process systems, and supporting instrumentation and control systems.

The Low Speed Wind Tunnel (LSWT) will have the following major features: closed circuit pressurized air wind tunnel with a removable plenum and test section, plenum and test section pressure/vacuum isolation system, and superior flow and data quality. The LSWT will also operate in an open-jet mode at 1 atmosphere with an anechoic chamber surrounding the open jet.

The Transonic Speed Wind Tunnel (TSWT) will have the following major features: closed circuit pressurized air wind tunnel with a removable plenum and test section, plenum and test section pressure/vacuum isolation system, and superior flow and data quality.

These tunnels will be highly productive, each one utilizing a removable plenum and test section cart system for rapid model changes. The primary focus of this complex is to provide test facilities with high productivity and reliability, superior flow and data quality, and low cost per data point.

### Assumed Generic Site Conditions

The fundamental requirements for site conditions are taken from the Site Selection Criteria and are given in Table 1.0. Exact values will be determined after a site is selected.

Table 1.0 Assumed Generic Site Conditions

Parameter	Requirement
Access Road	Within 2250 feet of site boundary
Transportation	Barge(preferred) or rail
Access to rail - shipping	Nearest siding 2 miles
Source of water - make up	Utility service at site boundary Operating capacity-7500 gpm
Electric Power	Total connected load-590 MW Maximum peak-500 MW 138 kv available at site boundary for start up 4.16 kv available at site boundary for construction
Natural gas service	Within 2000 feet from site boundary Peak demand-3500 scfm Average demand-100-200 scfm Operating pressure-50 psig Projected annual usage-200-400 Mscfm
Sewage system	Within 2000 feet from site boundary
Cooling Water	
Mechanical draft cooling towers	
Designed for summer conditions (75 ° F wet bulb)	
Projected Temperatures	Max. ( ° F)      Base ( ° F)
Ambient	95                  60
Wet bulb	75                  52
Temperature approach	10                  19
Cold water	85                  71
Temperature rise	20                  20
Return temperature	105                  105

**NSWC Requirements:****Productivity**

Productivity is one of the primary goals for these facilities. For an operating wind tunnel, productivity can be improved in a variety of ways. The ability to take data quickly and to articulate and manipulate the model quickly and accurately is one element of productivity. Another element of productivity is to reduce the time associated with all maintenance of, access to, and handling of elements. Other elements of productivity include reliability and maintainability. Redundant components might be required in critical areas so downtime to the facility can be minimized. Any component which has a significant probability of failure, which is critical to the complex operation, needs to be in stock at the facility or available from a

supplier, ready for immediate delivery. Overall facility productivity goals will be determined in terms of equivalent data polars per occupancy hour and fan-on hour.

## **Maintenance**

Minimizing facility and component "down-time" is a fundamental requirement to the NWTC. This will allow for the tunnel to be available to users whenever it is needed. In addition to concepts such as reliability and redundancy to minimize down-time, other issues such as ensuring commonality of components and thus reducing the time to find the correct part to perform a task. Considering access to components when maintenance is required so that maintenance personnel can physically fit/use the tools required is another fundamental requirement. However, the most efficient means of minimizing "down-time" of a component is to recognize when maintenance is required and then performing that maintenance at the next available opportunity. This is the concept behind Predictive Maintenance. Utilizing Predictive Maintenance will prevent taking components off-line until they need attention. Routine replacements of fluids may be included, however, repairs will be performed when it is indicated that repairs or maintenance are required. Predictive Maintenance depends upon numerous sensors on each component or system, a sufficiently large data base to describe the types of problems that may be encountered and the probable area of concern, a method of performing Trend Analysis to determine if a parameter is out of tolerance, as well as a means of user input and output. The tenets of Predictive Maintenance are much broader than as described herein, however, the benefits of this type of system are numerous. The number of staff required to operate and maintain the equipment can be minimized. Utilizing Predictive Maintenance will allow maintenance schedules to be developed as required. The NWTC design will provide for an integrated data acquisition and analysis system that will provide input to the Predictive Maintenance and Trending Analysis System. This system will provide information and recommendations to the users. The use of Predictive Maintenance will minimize the downtime of the components and systems and thus maximize the available operating time of the facility.

Wherever possible, commercially available equipment shall be specified. In addition, use common or "off the shelf" type of sizes. Basically, this means minimize the custom components. Use modular designs wherever possible, which simplifies construction and maintenance.

## **Accessibility**

Fundamental to improved productivity is reduced maintenance time. Numerous maintenance hours are routinely expended in obtaining access to components and systems and recovering these systems. This process will be significantly reduced through the appropriate use of automated access and improved access. Access for the NWTC shall be:

1. All sensors shall be accessible so that within XX minutes of initiating the access activity, the desired access can be obtained. Access is defined as meaning either complete removal of the sensor, or having sufficient clearance to get to all adjustments for in situ adjusting, or having sufficient clearance to get to all adjustments for calibration and sufficient room to connect all calibration instruments.

2. All routine maintenance items such as grease fittings, etc. can be accessible within **XX** minutes of initiating the access activity.
3. All fluids (liquids and gases) can be routinely sampled. All fluid systems shall include sampling connections to isolate sampling points. The sampling points shall be such that access can be obtained within **X** minute and that sufficient space is allotted for the sample container.
4. All components (electrical, mechanical, etc.) have as a minimum, sufficient space around, in, and near the component to allow for access, disassembly, rigging, handling, etc.
5. All buildings shall be configured so that egress/ingress pathways are available for all components that could be removed (in other words, leave enough space to get the biggest single piece out without having to remove many interferences).
6. All accesses to the tunnels shall be configured according to the following schedule:
  - (a) All personnel accesses shall be either automatically actuated, or provide a mechanical dogging/latching mechanism. Fasteners shall not be used.
  - (b) The tunnel compressors shall have sufficient access so that personnel access to all rotor and stator blades can be obtained within **XX** minutes. The access shall be sufficient to allow a complete rotor and stator blade inspection. In addition, the access shall be sufficient to allow for removal of the rotor and stator blades individually. The access shall be either through a mechanical latching/dogging mechanism or through an automatic access.
  - (c) All other accesses (including the plenums and test sections) shall be automatically actuated to allow for access. This includes the penetration panels for instrumentation feed through. Those accesses that are used no more than once every **X** years can be isolated using fasteners if desired.
7. Access to all of the tunnel internals (screens, honeycomb, turning vanes, and heat exchanger) shall be such that access can be gained to all sides, access can be gained through automated hatches, and installation and/or use of the tunnel cleaning system and component inspection system, can be accomplished within **XX** minutes. The tunnel accesses shall be such that modules of the tunnel internals can be easily installed and or removed. Access to the tunnel isolation valve mechanisms and actuation devices shall also be considered.

## Handling of Components

Handling of components is a time consuming operation. Sufficient clearance will be provided around all components for removal and handling of the components. Overhead cranes will be provided in all areas where handling of equipment will be performed. The crane capacity will be sufficient to lift the largest single piece of equipment requiring removal. Sufficient pad eyes and lower capacity cranes will be provided to ensure the capability to remove equipment. Handling of components inside of both of the tunnel circuits will be considered. Padeyes or lifting lugs are acceptable provided they are not located in the flow stream. Any and all components inside the tunnel may have to be removed. Handling of these elements shall be considered.

## Commonality

Commonality of components is another means of ensuring the productivity requirements. This will allow for a reduced inventory of spare parts. It will also reduce the amount of training all personnel will have to undergo (personnel will not have to "know" 5 different pieces of equipment to perform the same function). Commonality of vendors for similar items of equipment is another requirement. The data acquisition system and the tunnel control system components shall be common between the two tunnels. This includes hardware, software, sensors, etc. In addition, the same philosophy shall be applied to the Auxiliary Process Systems. Another fundamental issue is to use the same sensor(s) for tunnel control and tunnel/model data acquisition. The cart systems shall be common between the two tunnels, recognizing that tunnel specific issues will have to be incorporated. This includes the model support system, the carts, and the rolling plenum. The isolation valve designs between the two tunnels shall be common.

## Safety and Reliability

Safety is not isolated from the design process. Safety, reliability, QA, productivity and personnel issues are an integral part of the design process. Personnel and equipment safety are fundamental requirements to the NWTC. Due to the totally integrated nature of this facility, it is not possible to separate those items that are only safety related. Safety shall be incorporated into the NWTC as a fundamental requirement. The NWTC reliability is a function of the system, sub-system, and component reliability. The NWTC will have an overall complex reliability of *TBD*. Means to achieve this can include (but are not limited to) specifying reliable system components and/or designing in system redundancy. The overall NWTC reliability needs to be considered in all phases of design and construction.

## Design Standards and Philosophies

Select the system units (metric or English). Utilize similar design philosophies between the two tunnels. This includes layouts, configurations, and non-dimensional units. The tunnels should incorporate "identical" control rooms. The control consoles shall be identical and located in the same locations. Consider separate data review/acquisition rooms for the separate customers. This means the control room will be "generic" and focus on the tunnel control and not the data

acquisition. The designs shall consider constructability. Design must be "robust". It must allow for expansion either in capability or performance envelope as well as physical expansion of the system(s). The design shall consider automation to the fullest extent practicable, with the thought towards minimizing station keepers. The design shall utilize common standards and designs. These include: (1) all drawings on CAD (need to specify a system), (2) common drawing layouts, (3) common drawing identifiers (e. g., wiring diagrams, process schematics - line numbers, etc.), (4) codes (ASME, IEEE, NEC, etc.), (5) hardware independent software (controls, data acquisition and reduction, etc.), and (6) a common framework for instrumentation uncertainty (AGAARD AR-306, ISO-9000)

## 1.1 SITE AND INFRASTRUCTURE

### 1.1.1 Site Preparation

The site preparation is dependent on site selection. The particular requirements and criteria in this section are **TBD** pending site selection.

#### 1.1.1.1 Clearing and Grubbing

**Definition:** Clear and grub any brush and vegetation as required for laydown and construction of the tunnels and other facilities.

**Requirement:** Brush and vegetation shall be removed to allow for construction of facilities. Removal of trees includes the root ball. Consideration shall be given to keeping existing trees that are not in the way of new construction. Extent of clearing and grubbing is **TBD** pending site selection.

**Criteria:** **TBD**

#### 1.1.1.2 Demolition

**Definition:** The demolition and removal of existing construction on the site that will not be reused.

**Requirement:** After determining the layout of the facilities, any existing construction or barriers to new construction shall be demolished and removed or relocated. Existing utilities that will remain active shall be rerouted or capped off as required. Extent of demolition is **TBD** pending site selection.

**Criteria:** **TBD**

### 1.1.2 Site Improvements

**Definition:** The scope includes all excavation, finished grading, drainage, paving, roads, parking lots, associated area lighting, landscaping, and utilities within the NWTC perimeter and extending existing utilities and transportation systems to the site. A roadway system within the perimeter ensures access to all tunnel or building areas during phased construction and for continued access and maintenance duties after the complex is completed. Extent and nature of site improvements is **TBD** pending site selection.

**Requirement:** Extent of site improvements is **TBD** pending site selection and development of the Master Plan.

**Criteria:** **TBD**

### 1.1.2.1 Earthwork

**Definition:** Cut and fill work to establish a uniform grade at the site. Mass excavation to prepare for structural foundations associated with the wind tunnels, utility tunnels and associated buildings. Backfill as required around the wind tunnel foundations and utility tunnels.

**Requirement:** Extent of earthwork is **TBD** pending site selection and design of foundations and underground construction.

**Criteria:** **TBD**

### 1.1.2.2 Drainage

**Definition:** A storm drainage system consists of catch basins, piping and culverts to collect and direct surface water run-off and direct it to an off-site retention pond. Discharge from the retention pond is directed to the storm sewer system.

**Requirement:** The extent of the storm drainage system is **TBD** pending site selection and layout of buildings.

**Criteria:** **TBD**

### 1.1.2.3 Roads and Paving

**Definition:** An access road is provided from existing roadway to the site. In addition, site perimeter roads, parking areas and concrete walkways are also provided.

**Requirement:** Road surfaces both onsite and those leading to the site must be capable of supporting interstate highway rated loads. Extent and nature of roads and paving is **TBD** depending on the site selection and final layout of the facilities.

**Criteria:** **TBD**

### 1.1.2.4 Landscaping

**Definition:** Minimal landscaping treatment as required by local standards is provided. Native trees, grasses and shrubs are preserved, where safety, operability and aesthetic considerations warrant.

**Requirement:** The extent of the landscaping is **TBD** pending site selection and layout of buildings.

**Criteria:** **TBD**

#### 1.1.2.5 Fencing and Gates

**Definition:** Security fencing is provided around various equipment locations and the perimeter of the site. Large truck/car gates, plus pedestrian access gates are provided in various locations.

**Requirement:** The extent of this work is *TBD* depending on the site selection, final layout of the facilities, and the extent of any existing security system.

**Criteria:** *TBD*

#### 1.1.2.6 Transportation Improvements

**Definition:** Major equipment modules may be fabricated off-site and delivered to the site. The maximum size or weight of these modules will be limited by the mode of transportation. This item provides construction or improvements to existing transportation systems to allow delivery of as large as possible sized components and modules.

**Requirement:** Extent and nature of transportation improvements is *TBD* depending on the site selection and development of a fabrication plan.

**Criteria:** *TBD*

#### 1.1.3 Utility Supply And Distribution System

**Definition:** The scope includes all site utilities (except for electrical power which is covered under Section 1.1.4) required for the operation of the NWTC. It does not include the installation of utilities internal to the wind tunnels or internal to other buildings.

##### 1.1.3.1 Water Supply and Treatment System

**Definition:** The scope includes providing cooling water for the main drives and auxiliary equipment and providing a potable water system.

**Requirement:** Depending upon the site selected, two alternatives for cooling of the tunnel main drives and auxiliary equipment have been identified. The first alternative for the cooling tower makeup water is to use a natural water source (e.g. river or lake) with a treatment system for the water source. The second alternative for the cooling tower makeup water is to use a municipal water source.

The intake structure for the natural water source and treatment system shall include trash-rack, debris screens, pumps, and piping. The use of a municipal water source will require pumps and piping approximately equal in capacity to the river water makeup source.

If the local well alternative is chosen as the source of potable water, multiple wells will be used. A basic filtering and chlorinating treatment system, storage tank(s), piping, and pumps shall be provided. The second alternative for the potable water is to use a municipal water source and a

storage tank. Depending upon the pressure available from the municipal water source, pumps may be needed. The amount of potable water storage shall provide all of the needs for the complex without external resupply for a period of **TBD** days.

Depending upon the site selected, two alternatives for potable water have been identified. The first alternative is to use well water with pumps, piping, and storage tanks as the source of potable water. The second alternative is to use a municipal water source, piping, and storage tanks. If pressure available from the municipal water source is insufficient, booster pumps shall be provided.

Criteria: **TBD**

#### **1.1.3.2 Sanitary Waste Water Collection and Treatment System**

Definition: The scope includes providing sanitary waste collection and treatment.

Requirement: Depending upon the site selected, two alternatives have been identified for providing sanitary waste water collection and treatment. If the site selected has a regional or local sewage treatment facility of sufficient capacity, the sewage shall be collected and pumped to this existing facility for treatment and discharge. If there is no existing treatment plant available, a dedicated treatment plant shall be constructed to treat the waste prior to discharge.

Criteria: **TBD**

#### **1.1.3.3 Natural Gas System**

Definition: The scope includes providing natural gas for heating of the facilities and for heating of process air.

Requirement: The natural gas system shall provide a distribution system including piping, pressure reducing station, metering, and valves to the facilities. Once the site has been selected, negotiations can proceed to determine if the natural gas utility company will provide the piping to the site and will provide the metering and pressure reducing station. Anticipated maximum natural gas demand is **TBD** standard cubic feet per minute (scfm). Projected annual usage is **TBD** million cubic feet.

Criteria: **TBD**

#### **1.1.3.4 Yard Fire Protection System**

Definition: The scope includes providing a fire suppression water system for the facilities.

Requirement: The yard fire protection system shall provide a water source, valves, piping, and fire hydrants for the fire suppression system. The water for fire suppression shall be obtained from the cooling tower basins using both electric motor driven and diesel engine driven pumps. A looped non-potable fire main shall supply water to the buildings for wet pipe and dry pipe

sprinkler systems. Approximately **TBD** water hydrants shall be installed throughout the site. It is assumed that mobile fire protection shall be provided from local municipal fire stations.

Criteria: **TBD**

#### 1.1.3.5 Compressed Air System

Definition: The scope includes providing a service air system for the complex.

Requirement: The compressed air system shall provide sufficient service air for the facilities. A **TBD** scfm, **TBD** psi compressed air system shall be required for shop service air usage throughout the site. Individual compressor modules shall also be provided at strategic locations.

Criteria: **TBD**

#### 1.1.4 Yard Electrical Power System

Definition: The scope includes the electrical power distribution system external to the facilities and required for the operation of the NWTC. It does not include the installation of electrical systems internal to the wind tunnels or internal to the other buildings.

##### 1.1.4.1 Electrical Equipment

Definition: The scope provides the distribution system and related switching, power conditioning, harmonic filtering, and voltage transformation equipment to enable the wind tunnel complex to utilize the power obtained from the utility company. It will also ensure that the appropriate power factor is maintained and that the generated harmonics are within acceptable guidelines.

Requirement: Depending upon voltage available from the electrical utility company, the delivered primary voltage could range from 115 kV to 230 kV. After the site is selected, negotiations will be held with the utility company to determine the exact voltage that will be delivered. The **TBD** kV power will be delivered to one main substation and two wind tunnel drive substations (one substation each for the Low Speed Wind Tunnel and the Transonic Speed Wind Tunnel). Medium and low voltage substations will provide power at nominally 4.16 kV and 480 volts. Power shall be distributed between the substations and equipment by power cables/busses in cable tunnels and/or ductbanks. The substations shall be strategically located to minimize the secondary cable/bus systems. Security lighting and fences will be provided.

**Table 1.1.4.1.a Power Distribution System Requirements**

Total connected load:	<i>TBD during PER</i>
Peak demand load:	<i>TBD during PER</i>
Average demand load:	<i>TBD during PER</i>
Average monthly electrical energy usage:	<i>TBD during PER</i>
Average monthly power factor:	<i>TBD during PER</i>
Voltage at interconnect with utility company:	<i>TBD during PER</i>
Voltages at interconnect with site substation network:	<i>TBD during PER</i>
Short circuit capacity:	<i>TBD during PER</i>
Ramp rate:	<i>TBD during PER</i>

Criteria: *TBD*

#### **1.1.4.2 Electrical Material**

Definition: Electrical material includes the cable, conduit, and cable tray required for control, protection, and metering.

Requirement: Furnish and install control, protection, and metering of the yard electrical system.

Criteria: *TBD*

#### **1.1.5 Other Electrical Systems**

##### **1.1.5.1 Lighting Systems**

Definition: Provide general area lighting for the complex.

Requirement: Area lighting shall be furnished and installed, except for security fence lighting which is covered under 1.1.5.3, in accordance with the Illuminating Society of North America standards for all exterior areas of the complex. Lighting for all outside support systems requiring 24 hour maintenance and/or operation shall have enhanced illumination levels. In areas where safety and/or security are important, the lighting shall be supplied by an uninterruptible power source or will automatically transfer to a diesel powered generator.

Criteria: *TBD*

##### **1.1.5.2 Communications Systems**

Definition: Provide communications system for the complex.

Requirement: Telephones and an intercom system shall be provided throughout the complex. Remote video/audio shall be provided in the yard, facility, and operational areas where safety

and/or security are required. Telephones, speakers, and microphones shall be provided to enable employees to readily and efficiently communicate with other facility employees. Remote video/audio systems shall be provided as determined during the final design to improve safety, security, and/or efficiency of operations.

Criteria: *TBD*

#### **1.1.5.3 Security Systems**

Definition: Provide security systems for the complex.

Requirement: Security systems including fencing, gates, security lighting, remote operated close circuit television (CCTV), alarms, and separate security communications shall be provided for the complex. Security intrusion alarms shall be provided at the main gates and at personnel gates.

Criteria: *TBD*

#### **1.1.5.4 Grounding**

Definition: Provide grounding systems for the complex.

Requirement: An electrical grounding system shall be provided to meet the National Electric Code, local codes, and utility company requirements.

Criteria: *TBD*

#### **1.1.5.5 Cathodic Protection**

Definition: Provide cathodic protection for electrical and other equipment and systems as required.

Requirement: A cathodic protection system shall be provided to reduce the corrosion of electrical components and equipment.

Criteria: *TBD*

#### **1.1.5.6 Lightning Protection**

Definition: Provide lightning protection for electrical equipment.

Requirement: A lightning protection system shall be provided to protect the electrical equipment from lightning strikes.

Criteria: *TBD*

#### 1.1.5.7 Freeze Protection

Definition: Provide freeze protection for selected equipment.

Requirement: A system to prevent freezing of exterior water filled lines shall be provided. the system shall be automated and thermostatically controlled. Failure of a section of the freeze protection system shall activate an alarm.

Criteria: *TBD*

#### 1.1.5.8 Environmental Monitoring (Weather)

Definition: Provide environmental monitoring system for the complex.

Requirement: Although the type of environmental monitoring required has not been defined, a cost allowance is included for a station to monitor weather, noise, emissions, effluents, or similar environmental factors for the NWTC site.

Criteria: *TBD*

#### 1.1.5.9 DC Power for Instrumentation

Definition: Provide DC power for instrumentation.

Requirement: A DC power supply shall be provided for the instrumentation systems.

Criteria: *TBD*

#### 1.1.5.10 480 VAC Distribution System

Definition: Provide the 480 volt auxiliary power distribution system.

Requirement: The 480 volt substation secondary switchgear and load centers; 480 volt motor control centers, power distribution panels; DC system equipment with batteries, chargers, distribution panels, and motor control; and the Uninterruptible Power System (UPS) with batteries, inverters, switching, and distribution panels; and wiring and cable tray/conduit systems shall be provided.

Criteria: *TBD*

#### 1.1.5.11 Low Voltage Electrical System

Definition: Provide the low voltage electrical system for the LSWT and TSWT.

Requirement: The 480 volt and lower electrical systems, including secondary switchgear and load centers; 480 volt motor control centers, power distribution panels; DC system equipment

with batteries, chargers, distribution panels, and motor control; and wiring and cable tray/conduit systems shall be provided. Also included is the raceway complex for the control systems and the data acquisition systems.

Criteria: *TBD*

## 1.2 BUILDINGS

### 1.2.1 Test Preparation and Control Buildings

#### 1.2.1.1 LSWT Test Preparation and Control Building

**Definition:** The LSWT Test Preparation Building is a facility with cart and plenum rooms, and tunnel control and data acquisition/customer computer rooms. There are transfer halls to provide access for moveable plenums and carts from the tunnel to the cart and plenum rooms and another hall to provide access for the models to the model shop, calibration labs and equipment storage warehouse and the TSWT Test Preparation Building. This is accomplished through an interconnecting transfer hall running through the center of the building. The building is configured and sized to accommodate wind tunnel components that will move through the building. The floor is continuous with the exception of the rails and joints. Sizes of rooms and halls required by wind tunnel components is *TBD* pending design of the moveable tunnel components.

There are two rooms large enough to accommodate either plenum section. There are four other rooms that provide floor space for the moveable carts on rails flush with the floor. There is a remote test checkout control panel in a TEMPEST protected control room inside each cart room and the open jet plenum room for conducting full pretest simulation of automated test sequencing.

**Definition:** The LSWT Test Preparation Building enclosure consists of a moment resisting space frame structure with siding and roofing. There are personnel and large access doors. The foundation is a reinforced concrete mat. Any other foundation considerations are *TBD* pending site selection. The structure is designed in accordance with applicable local codes concerning seismic and wind loads. There is a hallway for personnel at ground level around the exterior perimeter of the building.

The LSWT control room is adjacent to the Low Speed Tunnel Enclosure Building. The control room houses computer-driven control systems for the LSWT. The LSWT computer room is adjacent to the LSWT control room. The computer room houses computer data acquisition systems.

Rails in the floor are provided for the moveable plenums and carts. An overhead bridge crane is provided in each of the cart rooms and the open jet plenum room. An overhead hoist is located at each exterior access door to facilitate unloading of models, components, and other equipment.

Heating, ventilation, and air conditioning is provided throughout the building. HVAC systems will be controlled to provide a slight positive pressure in the building to eliminate infiltration of unconditioned air. Fire protection is provided by automatic sprinkler fire suppression system. There are hose cabinets near main access doors and in each cart room.

Convenience receptacles are provided throughout the building. Other receptacles and disconnects are provided for specialized equipment connections. High bay lighting is provided

throughout the building. Smoke detectors and pull stations are tied into a fire alarm panel which is connected to the fire station. Special grounding and isolated power systems are required for computer equipment.

Requirement: The building structure shall support walls, roof, roof structure, and crane loads. Columns may be incorporated in wall structure, but should not be placed within open floor space. Access doors large enough to allow passage of the component for which the room is designed shall be provided for each of the cart and plenum rooms. Access doors shall be provided at either end of the central transfer hall and at the exterior end of the Test Preparation Building transfer hall. All large access doors shall be motor operated. Personnel doors shall be built into the bottom of the large access doors. Storm water runoff shall be collected in a guttering/roof drain system and discharged into the underground storm water system. Smoke vents shall be provided on the roof.

The layout, size, and function of each of the cart and plenum rooms is driven by the design of the rolling plenums and the model carts. The floors shall have rails flush with the floor to allow the model cart to be rolled from the moveable plenum or shuttle cart into the cart room. In the cart rooms there shall be access around three sides of the cart at the same elevation as the cart floor. There shall be a raised computer flooring in each of the control checkout rooms. Large rolling doors in the central transfer hall shall provide access for the carts into the cart room. Personnel access into the room shall be provided by a door into the central transfer hall and an emergency exit into the perimeter hallway. Access shall be limited by a controlled lock system. There shall be a unisex toilet in each cart room. Two of the rooms shall also be equipped for continuous flow high pressure air for model engine simulation. One of the cart rooms shall have continuous flow, high pressure air capability and the open jet plenum storage room shall have continuous flow, lower pressure air capability. The requirements for the pressurized air are listed in Section 1.3, **AUXILIARY PROCESS SYSTEMS**. Each of these two rooms shall be provided with an exhaust connection to a roof mounted muffler tower and over pressure blow-out provisions shall be incorporated. Only one of these rooms shall utilize the air capability at a time.

The LSWT Control and Computer Rooms are typical computer rooms. The LSWT control room is adjacent to the Low Speed Tunnel Enclosure Building. Each room has raised computer room flooring. The Control Room houses computer-driven control systems for the LSWT. Personnel access into the control room shall be provided by two doors into the LSWT enclosure and one to the LSWT Computer Room. There shall be windows in the wall between the Control Room and the LSWT enclosure. The LSWT Computer Room is adjacent to the LSWT control room and houses computer data acquisition systems. Access to both rooms shall be limited by a controlled lock system. Each room shall have its own independent HVAC system. The sizes of these rooms are **TBD** depending on final design and layout of the control and data acquisition equipment.

An overhead bridge crane, rated at **TBD** tons, shall be provided in each of the cart and plenum rooms for lifting models and other pieces of equipment. All cranes shall be motor operated. Cart and plenum rails shall be flush with the floor. There shall be provisions for allowing the

moveable plenum and open jet cart to move down the central transfer hall and be moved in a perpendicular direction to a storage room.

The location of all mechanical and electrical systems shall not interfere with the operation of cranes, doors, and moving components. Mechanical equipment shall be located so that it may be easily accessed and serviced. Any piece of equipment requiring routine maintenance shall be no more than ten feet above a permanent working surface, otherwise catwalk and platform access shall be provided. Electrical service shall be provided to all mechanical equipment, motor operated doors, and cranes. Smoke detectors shall be provided in each cart room and computer room. Pull stations shall be located on the wall near each personnel access door. These fire detection devices shall be connected to a building fire alarm panel which is tied to the fire station.

Criteria: *TBD*

#### 1.2.1.2 TSWT Test Preparation and Control Building

Definition: The TSWT Test Preparation Building is a facility with cart rooms, and tunnel control and data acquisition/customer computer rooms. There are transfer halls to provide access for carts from the tunnel to the cart rooms and another hall to provide access for the models to the model shop, calibration labs and equipment storage warehouse and the LSWT Test Preparation Building. This is accomplished through an interconnecting transfer hall running at the end of the building. The building is configured and sized to accommodate wind tunnel components that will move through the building. The floor is continuous with the exception of the rails and joints. Sizes of rooms and halls required by wind tunnel components is *TBD* pending design of the moveable tunnel components.

Definition: The TSWT Test Preparation Building enclosure consists of a moment resisting space frame structure with siding and roofing. There are personnel and large access doors. The foundation is a reinforced concrete mat. Any other foundation considerations are *TBD* pending site selection. The structure is designed in accordance with applicable local codes concerning seismic and wind loads. There is a hallway for personnel at ground level around the exterior perimeter of the building.

There are four rooms that provide floor space for the moveable carts on rails flush with the floor. There is a remote test checkout control panel in a TEMPEST protected control room inside each cart room for conducting full pretest simulation of automated test sequencing.

The TSWT control room is adjacent to the Transonic Speed Tunnel Enclosure Building. The control room houses computer-driven control systems for the TSWT. The TSWT computer room is adjacent to the TSWT control room. The computer room houses computer data acquisition systems.

Rails in the floor are provided for the moveable plenums and carts. An overhead bridge crane is provided in each of the cart rooms. An overhead hoist is located at each exterior access door to facilitate unloading of models, components, and other equipment.

Heating, ventilation, and air conditioning is provided throughout the building. HVAC systems will be controlled to provide a slight positive pressure in the building to eliminate infiltration of unconditioned air. Fire protection is provided by automatic sprinkler fire suppression system. There are hose cabinets near main access doors and in each cart room.

Convenience receptacles are provided throughout the building. Other receptacles and disconnects are provided for specialized equipment connections. High bay lighting is provided throughout the building. Smoke detectors and pull stations are tied into a fire alarm panel which is connected to the fire station. Special grounding and isolated power systems are required for computer equipment.

**Requirement:** The building structure shall support walls, roof, roof structure, and crane loads. Columns may be incorporated in wall structure, but should not be placed within open floor space. Access doors large enough to allow passage of the component for which the room is designed shall be provided for each of the cart and plenum rooms. Access doors shall be provided at either end of the central transfer hall and at the exterior end of the Test Prep Building transfer hall. All large access doors shall be motor operated. Personnel doors shall be built into the bottom of the large access doors. Storm water runoff shall be collected in a guttering/roof drain system and discharged into the underground storm water system. Smoke vents shall be provided on the roof.

The layout, size, and function of each of the cart rooms is driven by the design of the model carts. The floors shall have rails flush with the floor to allow the model cart to be rolled from the moveable plenum or shuttle cart into the cart room. There shall be access around three sides of the cart at the same elevation as the cart floor. An overhead bridge crane shall be provided in each of the rooms for lifting models and other pieces of equipment. There shall be a raised computer flooring in each of the control checkout rooms. Large rolling doors in the central transfer hall shall provide access for the carts into the cart room. Personnel access into the room shall be provided by a door into the central transfer hall and an emergency exit into the perimeter hallway. Access shall be limited by a controlled lock system. There shall be a unisex toilet in each cart room. One of the rooms shall also be equipped for continuous flow high pressure air for model engine simulation. One of the cart rooms shall have continuous flow, high pressure air capability. The requirements for the pressurized air are listed in Section 1.3, AUXILIARY PROCESS SYSTEMS. This room shall be provided with an exhaust connection to a roof mounted muffler tower and over pressure blow-out provisions.

The TSWT Control and Computer Rooms are typical computer rooms. The TSWT control room is adjacent to the Low Speed Tunnel Enclosure Building. Each room has raised computer room flooring. The Control Room houses computer-driven control systems for the TSWT. Personnel access into the control room shall be provided by two doors into the TSWT enclosure and one to the TSWT Computer Room. There shall be windows in the wall between the Control Room and

the TSWT enclosure. The TSWT Computer Room is adjacent to the TSWT control room and houses computer data acquisition systems. Access to both rooms shall be limited by a controlled lock system. Each room shall have its own independent HVAC system. The sizes of these rooms are *TBD* depending on final design and layout of the control and data acquisition equipment.

An overhead bridge crane, rated at *TBD* tons, shall be provided in each of the cart rooms for lifting models and other pieces of equipment. All cranes shall be motor operated. Cart and plenum rails shall be flush with the floor. There shall be provisions for allowing the moveable plenum to move down the central transfer hall and be moved in a perpendicular direction to a storage room.

The location of all mechanical and electrical systems shall not interfere with the operation of cranes, doors, and moving components. Mechanical equipment shall be located so that it may be easily accessed and serviced. Any piece of equipment requiring routine maintenance shall be no more than ten feet above a permanent working surface, otherwise catwalk and platform access shall be provided. Electrical service shall be provided to all mechanical equipment, motor operated doors, and cranes. Smoke detectors shall be provided in each cart room and computer room. Pull stations shall be located on the wall near each personnel access door. These fire detection devices shall be connected to a building fire alarm panel which is tied to the fire station.

## 1.2.2 Tunnel Enclosure And Drive Buildings

### 1.2.2.1 LSWT Enclosure

The LSWT Enclosure is a building surrounding the tunnel pressure shell serving two main purposes: (1) To provide a more stable controlled environment for the tunnel shell since operating conditions and hence test results would be compromised, and (2) reduce sound emanating from the LSWT to acceptable levels on site and at the site boundary.

**Definition:** The LSWT Enclosure Building consists of a moment resisting space frame structure with insulated siding and roofing. There are personnel and large access doors. The foundation is incorporated with the foundation for the LSWT, Section 1.4.1.1. The structure is designed in accordance with applicable local codes concerning seismic and wind loads.

The inner surfaces of the walls and roof are lined with insulation. The purpose of the insulation is to reduce the noise transmitted through the walls and roof, and to thermally insulate the building.

Overhead bridge cranes, *TBD* ton (minimum) capacity each, service the tunnel circuit, equipment and laydown space. The overhead bridge cranes shall be capable of lifting *TBD* components.

Basic building electrical services including high bay lighting, and convenience and special purpose outlets that are located at multiple locations within the building. Data, communication, and fire alarm services are provided.

**Requirement:** The steel structure shall support the walls, roof, roof structure, and crane loads. Columns shall be kept to a minimum. The location of these columns shall be dependent on the size and location of the LSWT. Access doors shall be provided, which are large enough to allow passage of any large components that might be expected to be replaced during routine maintenance activities or those components which might be damaged (e.g. compressor fan blades) by debris going downstream. The lower eight feet of the inside exterior wall shall be a finished surface. All large access doors shall be motor operated. Personnel doors shall be located adjacent to the large access doors and in other locations as required by local codes. Storm water runoff shall be collected in a guttering/roof drain system and discharged into the underground storm water system. Smoke vents shall be provided on the roof. The thickness and type of insulation is dependent on the noise generated by the LSWT and site selected (what level of noise is permissible at the fence line of the NWTC). Cranes shall be capable of servicing the tunnel circuit, equipment and laydown space within the enclosure. Cranes shall be capable of servicing the tunnel circuit, equipment and laydown space within the enclosure. Cranes shall be motor operated. Fire protection is provided by mobile equipment. The location of all mechanical and electrical systems shall not interfere with the operation of cranes, doors, and moving components. Mechanical equipment shall be located so that it may be easily accessed and serviced. Any piece of equipment requiring routine maintenance shall be no more than ten feet above a permanent working surface, otherwise catwalk and platform access shall be provided. Electrical service shall be provided to all mechanical equipment, motor operated doors, and cranes. Smoke detectors shall be provided in each cart room and computer room. Pull stations shall be located on the wall near each personnel access door. These fire detection devices shall be connected to a building fire alarm panel which is tied to the fire station.

#### 1.2.2.2 TSWT Enclosure

The TSWT Enclosure is a building surrounding the tunnel pressure shell serving two main purposes: (1) To provide a more stable controlled environment for the tunnel shell since operating conditions and hence test results would be compromised, and (2) reduce sound emanating from the TSWT to acceptable levels on site and at the site boundary.

**Definition:** The TSWT Enclosure Building consists of a moment resisting space frame structure with insulated siding and roofing. There are personnel and large access doors. The foundation is incorporated with the foundation for the TSWT, Section 1.5.1.1. The structure is designed in accordance with applicable local codes concerning seismic and wind loads.

The inner surfaces of the walls and roof are lined with insulation. The purpose of the insulation is to reduce the noise transmitted through the walls and roof, and to thermally insulate the building.

Overhead bridge cranes, **TBD** ton (minimum) capacity each, service the tunnel circuit, equipment and laydown space. The overhead bridge cranes shall be capable of lifting **TBD** components.

Basic building electrical services including high bay lighting, and convenience and special purpose outlets that are located at multiple locations within the building. Data, communication, and fire alarm services are provided.

**Requirement:** The steel structure shall support the walls, roof, roof structure, and crane loads. Columns shall be kept to a minimum. The location of these columns shall be dependent on the size and location of the TSWT. Access doors shall be provided, which are large enough to allow passage of any large components that might be expected to be replaced during routine maintenance activities or those components which might be damaged (e.g. compressor fan blades) by debris going downstream. The lower eight feet of the inside exterior wall shall be a finished surface. All large access doors shall be motor operated. Personnel doors shall be located adjacent to the large access doors and in other locations as required by local codes. Storm water runoff shall be collected in a guttering/roof drain system and discharged into the underground storm water system. Smoke vents shall be provided on the roof. The thickness and type of insulation is dependent on the noise generated by the TSWT and site selected (what level of noise is permissible at the fence line of the NWTC). Cranes shall be capable of servicing the tunnel circuit, equipment and laydown space within the enclosure. Cranes shall be motor operated. Fire protection is provided by mobile equipment. The location of all mechanical and electrical systems shall not interfere with the operation of cranes, doors, and moving components. Mechanical equipment shall be located so that it may be easily accessed and serviced. Any piece of equipment requiring routine maintenance shall be no more than ten feet above a permanent working surface, otherwise catwalk and platform access shall be provided. Electrical service shall be provided to all mechanical equipment, motor operated doors, and cranes. Smoke detectors shall be provided in each cart room and computer room. Pull stations shall be located on the wall near each personnel access door. These fire detection devices shall be connected to a building fire alarm panel which is tied to the fire station.

### 1.2.2.3 LSWT/TSWT Drive Building

This building houses the drive systems for both tunnels including the drive motors for the LSWT and the TSWT. The building also houses all of the associated variable speed motor controls, couplings, lubrication, and cooling systems for each drive system. Cooling ductwork, storage and maintenance space is provided under each pedestal. Drive controls, power supply and conditioning system and motor cooling (air to water heat exchangers) system are located outdoors adjacent to drive building.

**Definition:** The building foundation consists of a reinforced concrete basemat with raised pedestals to support each of the drive systems. The foundation for each drive system is common to the corresponding isolated compressor foundation to prevent differential movement between the drive systems and the compressors, but isolated from the other motor foundation. Any other foundation considerations are **TBD** pending site selection.

The LSWT/TSWT Drive Building enclosure consists of a moment resisting space frame structure with insulated siding and roofing. There are personnel doors and a large access door. The structure is designed in accordance with applicable local codes concerning seismic and wind loads. The inner surfaces of the walls and roof are lined with insulation. The purpose of the insulation is to reduce the noise transmitted through the walls and roof, and to thermally insulate the building. The overhead bridge crane, **TBD** ton (minimum) capacity, services the equipment and laydown space. Fire protection is provided by mobile equipment. Hose cabinets are included by main access doors. Service air outlets are located at multiple locations within the building. Heating and exhaust fans are provided. Basic building electrical services include power to the motor control centers, high bay lighting, and convenience and special purpose outlets that are located at multiple locations within the building. Communication and fire alarm services are provided.

**Requirement:** The foundation for the drive motors is dependent on the configurations of the motors and the site conditions. The structure shall support the walls, roof, roof structure, and crane loads. Columns shall be on the exterior wall only with the central space clear of obstructions. The access door shall be large enough to allow passage of the largest drive motor component loaded on a trailer and to be off-loaded inside the building. The lower eight feet of the inside exterior wall shall be a finished surface. The large access door shall be motor operated. Personnel doors shall be located adjacent to the large access doors and in other locations as required by local codes. Windows shall be located on the two side walls. Storm water runoff shall be collected in a guttering/roof drain system and discharged into the underground storm water system. Smoke vents shall be provided on the roof. The crane shall be capable of lifting **TBD** components and spanning the entire width of the building. Heating, ventilation, and air conditioning is provided throughout the building. Protection is provided by automatic sprinkler fire suppression system. There are hose cabinets near main access doors. Electrical services including power to the motor control centers, high bay lighting, and convenience and special purpose outlets that are located at multiple locations within the building. Communication and fire alarm services are provided.

### 1.2.3 Support Buildings

#### 1.2.3.1 Model Shop/Warehouse

The Model Shop is a heavy duty structure interconnected with the LSWT Test Preparation/Control Building and the TSWT Test Preparation/Control Building. The building houses a Machine Shop including heavy and light machine tools and assembly areas for repairing test models and test equipment, an Air Calibration Shop, a Balance Calibration Shop, an Electronics Shop, and a vertical stacking test Warehouse/Storage area. The warehouse is accessed from the exterior through a large motorized access door in the laydown area in the shop. There is an internal office tower over the shop area on which has multiple levels with additional floor space for a Shop and Test Engineering Area, a Photo Laboratory, a Medical Room, an administration area, conference rooms, planning rooms, rest rooms, and customer areas.

The shop is divided into two working areas and connects with a matching corridor from the LSWT Test Preparation and Control building to the TSWT Test Preparation and Control building. This central corridor permits transport of test carts/test sections and/or test models from either of the tunnels/cart rooms into the shop for setup or rework and maintenance. On one side of the corridor is a laydown high bay area next to the machine shop and an equipment storage area.

The other half of the shop consists of model and test setup/fixtures fabrication and repair equipment and work areas. Also on this side are the Air Calibration Laboratory, Balance Calibration lab, Structural Calibration lab, and the Electronics Shop. An internal office tower is located next to the elevators between the shop and the test prep/control building and extends 5 stories high above the ground floor.

This Model Shop/Warehouse building has a service mission. The required functions are only suggested ones and shall be determined as the design progresses and is dependent on those, if any, existing functions at the selected site. The foundation consists of a reinforced concrete mat plus any other foundation considerations which are *TBD* pending site selection. The Balance Calibration area, capable of resisting balance loads as described in Section 1.3, AUXILIARY PROCESS SYSTEMS, is a rigid massive isolated foundation. All other areas share a common foundation.

The building structure is a moment resisting space frame with insulated siding, overhead and safety lighting. The internal office tower has additional floor space on multiple levels and offers office type space for the other functional areas. The structure is designed in accordance with applicable local codes concerning seismic and wind loads. There is space for numeric control programming and shop planners along with office, administrative, conference, and customer areas on upper floors above the shop area. The Photo Laboratory houses photographic development equipment and processes all site photographic data.

The Photo Laboratory shall be TEMPEST shielded and secure operations and storage. The Balance Calibration Laboratory houses equipment for calibrating external and internal balances for site and has easy access to the cart rooms. The Structural Calibration Laboratory houses equipment for calibration of modal analysis of models in a portion of support shop located next to balance and Air Calibration labs. There is easy access to the cart rooms of both model/prep buildings. The Air Calibration Laboratory contains airflow measuring equipment and static thrust facility. The facility includes exhaust muffler tower on roof. There is an source of high pressure air as described in Section 1.3, AUXILIARY PROCESS SYSTEMS, at point of use plus a source of vacuum. There is easy access to the cart rooms. The Electronics Shop area is provided to support those needs of the LSWT and TSWT.

The Warehouse/Storage area is for storage of models and components. It is walled off for security. It has a semi-automated stacking crane. The module/rack size is adjustable to fit whatever storage requirements are determined within the total volume set and the aisleway configuration selected. Covered and locked pallets are used to store models and test accessories.

There are a number of underhung bridge cranes with capability of moving full hanging load throughout high bay shop area to any point inside connected test prep/control building including through open sliding doors. Two combination personnel and freight/maintenance elevators are at either end of this building connecting with the Shop/Office/Test Preparation Buildings. One elevator serves the first 2 floors and the other serves all 5 floors and roof of building for maintenance of HVAC units and vertical door hoist house equipment.

Heating, ventilation, and air conditioning is provided throughout the building. Protection is provided by automatic sprinkler fire suppression system. There are hose cabinets near main access doors. Electrical services including high bay lighting, and convenience and special purpose outlets that are located at multiple locations within the building. Data, communication, and fire alarm services are provided.

**Requirement:** The foundation design is **TBD** depending on the building layout and the site conditions. The enclosure shall be sized, laid out and designed to meet the final requirements of the functional work groups that will be housed in the building. These requirements are **TBD**.

The requirements for the various calibration laboratories and other shops are **TBD** depending on site selection and the capability, if any, of existing photo Laboratory, Balance Calibration, Structural Calibration, Air Calibration, and electronics and machine shop facilities

The requirements are for the mechanical and electrical services are **TBD** pending site selection.

**Criteria:** **TBD**

#### 1.2.3.2 Compressor/Vacuum Station Building

The Compressor/Vacuum Station Building houses the wind tunnel air pressurization and vacuum system compressors, motors, and associated electrical, control and lubrication equipment.

**Definition:** The foundation for the building serves two functions: (1) to support the building structure, compressor, vacuum pumps and ancillary equipment, and (2) to serve as the basement floor. The enclosure consists of a moment resisting space frame structure with insulated siding and roofing. There are personnel doors and large access doors. The structure is designed in accordance with applicable local codes concerning seismic and wind loads. The basement provides space to run process piping and a location for compressor ancillary equipment. Cooling system heat exchangers are located in the basement.

There are overhead bridge cranes servicing the compressors, vacuum pumps, and ancillary equipment.

Heating, ventilation, and air conditioning is provided throughout the building. Protection is provided by automatic sprinkler fire suppression system. There are hose cabinets near main access doors. Electrical services including high bay lighting, and convenience and special purpose outlets that are located at multiple locations within the building. Data, communication, and fire alarm services are provided.

**Requirement:** The Compressor/Vacuum Station Building enclosure consists of a moment resisting space frame structure with insulated siding and roofing. The foundation is a reinforced concrete basemat plus any other foundation considerations which are **TBD** pending site selection and equipment requirements. The structure is designed in accordance with applicable local codes concerning seismic and wind loads and shall support the walls, roof, roof structure, and crane loads. Columns shall be on the exterior wall only with the central space clear of obstructions. An elevated, prefabricated modular control room shall be located on the first floor. Access doors shall be large enough to allow passage of the large equipment. There are personnel doors and large access doors. Personnel doors shall be located in locations as required by local codes. All large access doors shall be motor operated. Windows shall be provided for natural lighting and ventilation. The inner surfaces of the walls and roof are lined with insulation. The purpose of the insulation is to reduce the noise transmitted through the walls and roof, and to thermally insulate the building.

Overhead bridge cranes, **TBD** ton (minimum) capacity, are capable of lifting the large components and span the entire width of the building. The capacity of the cranes is **TBD**.

Storm water runoff shall be collected in a guttering/roof drain system and discharged into the underground storm water system. Fire protection is provided by mobile equipment. Hose cabinets are included by main access doors. Service air outlets are located at multiple locations within the building. Heating and exhaust fans are provided. Smoke vents shall be provided on the roof. Basic building electrical services include power to the motor control centers, high bay lighting, and convenience and special purpose outlets that are located at multiple locations within the building. Communication and fire alarm services are provided.

#### 1.2.3.3 Compressor Blade Shop

**Definition:** This building provides an area for repairs to compressor blades and a storage facility for spare blades.

**Requirement:** The compressor blade shop shall be a pre-engineered building with insulated siding and overhead and safety lighting. The foundation shall be a reinforced concrete slab on grade with thickened areas under walls and columns. Heating and ventilation shall be provided. Standard convenience electrical services are provided. Specific mechanical and electrical services required to support the installed machinery are **TBD**.

**Criteria:** **TBD**

#### 1.2.3.4 Utility Tunnels

**Definition:** Utility tunnels are provided to allow below grade piping and electrical commodities routing between major facilities such as the two wind tunnels, drive buildings, and test/preparation buildings, and the associated support facilities.

**Requirement:** The tunnels shall be underground and provide ample space for all the utilities plus area for safe passage of personnel. Lighting, emergency telephones, and sumps and pumps shall be located throughout the tunnel system. Natural ventilation vents shall be provided. Access shall be gained into the tunnels through each building and at various locations along the circuit. Layout is **TBD** depending on site Master Plan.

**Criteria:** **TBD**

#### 1.2.4 Operations

##### 1.2.4.1 Engineering Building

**Definition:** The Engineering Building provides engineering and administrative offices to partially serve the personnel supporting the operation of the wind tunnels. The remainder of the facility office space is located in the Model Shop/Warehouse Building. Included in the office area are planning rooms, teleconference rooms, and customer areas. Also included in this building is a cafeteria and food kitchen.

**Requirement:** This shall be a pre-engineered structure with insulated siding. The foundation shall consist of spread footings and grade beams, with slab on grade. Finishes shall be those of a typical office building. Heating, ventilation, and air conditioning shall be provided throughout the building. Protection shall be provided by automatic sprinkler fire suppression system. There shall be hose cabinets near main access doors. A fire alarm panel (with smoke detectors and pull stations) tied to the fire station shall be provided. Some functions are site dependent and **TBD** pending site selection.

**Criteria:** **TBD**

##### 1.2.4.2 Guard House

**Definition:** This building houses security personnel and supports associated security functions.

**Requirement:** This shall be a pre-engineered building with insulated siding and windows, and overhead and safety lighting. The foundation shall be a reinforced concrete slab on grade with thickened areas under walls and columns. Finishes shall be those of an typical office building. Heating, ventilation, and air conditioning shall be provided for the building. Fire protection shall be provided by automatic sprinkler fire suppression system, a hose cabinet near the main access door, and a fire alarm panel tied to the fire station. Smoke detectors and pull stations shall be tied into this panel.

**Criteria:** **TBD**

#### 1.2.4.3 Outfitting

**Definition:** This category includes items necessary during activation and operation of the NWTC.

Various vehicles will be required for maintenance, security operations, and materials and equipment handling. The suggested list of vehicles includes pickup trucks, security vehicles, fork lifts, and a high reach lift vehicle.

The machine shop includes heavy and light machine tools and assembly areas for repairing test models and test equipment. The suggested list of equipment includes lathes, mills, drill presses, various hand tools, presses, welding machines and other miscellaneous hand tools.

Diagnostic, test, and repair equipment is used for preventive maintenance and for troubleshooting problems with tunnel and auxiliary equipment when the need arises. Having this diagnostic equipment on hand helps maintain reliability and productivity of the complex. Suggested equipment includes power distribution test equipment, power distribution system tools, facility test equipment, mechanical systems diagnosis equipment, and pipe shop equipment.

Furniture is located in every building. Desks, chairs, and other specialized furniture is most heavily concentrated in the office and administrative areas. Personal computers and software used by administrative, engineering and clerical personnel.

Computer Automated Engineering System equipment is used for computer graphics design and numerical control generation of aeronautical and facility drawings. The data files are stored locally and all workstations as well as personal computers are linked to a mass storage system through a local area network.

Telephones are located throughout the complex. There is a central switching station which ties the individual phones to the local utility system. Telephones in designated secure areas shall have appropriate security features.

**Requirement:** The requirements for all of these categories are **TBD** depending on personnel (size and makeup of staff), final design, the needs of complex, and any existing equipment.

**Criteria:** **TBD**

### 1.3 AUXILIARY PROCESS SYSTEMS

**Definition:** The auxiliary process systems include the ancillary support systems that are used for providing air (low pressure and high pressure) and the complex cooling water system for use at the two wind tunnels, calibration facilities, and other users as are required. Specifically, the auxiliary process systems include low pressure air system, high pressure air system, vacuum system, cooling system, calibration facilities, low voltage electrical system, and the associated integrated systems testing activities.

**Requirements:** The requirements for the auxiliary process systems are generated from the two wind tunnels. The wind tunnel requirements are provided in sections 1.4 (LSWT) and 1.5 (TSWT). The specific system requirements that have been derived from the wind tunnel requirements, overall reliability requirements, productivity requirements, etc. are enumerated in the subordinate sections of the auxiliary process systems. Operationally, the auxiliary process systems allow for essentially unrestricted parallel operation of the two wind tunnels.

#### 1.3.1 Low Pressure Air System

**Definition:** The low pressure air system is used to: (1) provide clean, dry compressed air for pressurizing both of the wind tunnel pressure shells, test sections, and plenums, (2) provide the first stage of evacuation of both of the tunnel pressure shells and test sections, (3) evacuate and then pressurize the tunnel circuits for reducing the tunnel air dew point, (4) maintaining tunnel pressure control within the specified tolerances, and (5) provide a source of compressed air for selected model propulsion simulations.

The system will be an interconnected one that allows for multitasking of components in order to reduce the overall complexity of the system while meeting the productivity requirements. The system is composed of four primary subsystems: (1) the low pressure air compressor system, (2) the low pressure air drying system, (3) the low pressure air storage system, and (4) the low pressure air distribution system.

**Requirements:** The low pressure air system operational requirements are provided in Table 1.3.1.a and the performance requirements are provided in Table 1.3.1.b.

Integrated control systems shall be provided with redundancy to accommodate any single point of failure without facility damage or personnel harm. Programmable Logic Controllers (PLC's) shall be used to the fullest extent practicable to provide interlocks, control of discrete devices, analog control loops, and a fiber digital data interface to the control room. Commands from the control room will provide coordination, initiation, and termination activities as well as process set points.

Table 1.3.1.a Low Pressure Air System Operational Requirements

Item	Requirement
1.	<p>Provide sufficient flow and storage capacity to simultaneously pressurize the LSWT pressure shell and the TSWT pressure shell from 1 atm. to the tunnel maximum design pressure within <i>TBD minutes (TBD during the PER)</i>.</p> <p>Provide sufficient flow and storage capacity to pressurize the LSWT shell from 1 atm. to the tunnel maximum design pressure within <i>TBD minutes (TBD during the PER)</i>.</p> <p>Provide sufficient flow and storage capacity to pressurize the TSWT shell from 1 atm. to the tunnel maximum design pressure within <i>TBD minutes (TBD during the PER)</i>.</p>
2.	<p>Provide sufficient flow capacity to simultaneously evacuate the LSWT shell and the TSWT shell from 1 atm. to the tunnel minimum design pressure within <i>TBD minutes (TBD during the PER)</i>. Achieving the minimum design pressure may be augmented using the vacuum system, Section 1.3.3.</p> <p>Provide sufficient flow capacity to evacuate the LSWT shell from 1 atm. to the tunnel minimum design pressure within <i>TBD minutes (TBD during the PER)</i>. Achieving the minimum design pressure may be augmented using the vacuum system, Section 1.3.3.</p> <p>Provide sufficient flow capacity to evacuate the TSWT shell from 1 atm. to the tunnel minimum design pressure within <i>TBD minutes (TBD during the PER)</i>. Achieving the minimum design pressure may be augmented using the vacuum system, Section 1.3.3.</p>
3.	Provide sufficient flow and storage capacity to meet the High Speed Civil Transport nozzle model propulsion simulation requirements. This also includes the meeting the specified heating requirements. Note that the heating method is <i>TBD during the PER</i> .
4.	Provide sufficient flow and storage capacity to meet the Ultra-High Bypass model propulsion requirements. <i>This requirement may be transferred to the high pressure air system after the low pressure air system performance requirements have been optimized. The optimization shall be performed during the PER.</i>
5.	Provide sufficient flow and storage capacity to allow for a change in either tunnel air dew point from 100% Relative Humidity to the tunnel design dew point at the required tunnel operating pressure within <i>TBD minutes (TBD during the PER)</i> .
6.	The compressor system may be designed to supply on demand and participate in facility electrical load leveling and main drive system soft start intelligent control. <i>This is a TBD during PER if this will be done.</i>

Table 1.3.1.b Low Pressure Air System Performance Requirements

Parameter	Requirement
Maximum Design Pressure (psig)	<i>TBD During PER</i>
Minimum Design Pressure (psig)	<i>TBD During PER</i>
Maximum Design Temperature (°F)	<i>TBD During PER</i>
Minimum Design Temperature (°F)	<i>TBD During PER</i>
Maximum Design Flowrate (pps)	<i>TBD During PER</i>
Absolute Particulate Size (i. e., filtration required-microns)	<i>TBD During PER</i>
Maximum Dewpoint at Design Pressure (°F)	<i>TBD During PER</i>
Maximum Oil Content at Design Pressure (ppm)	<i>TBD During PER</i>
Overall Low Pressure Air System Reliability (%)	<i>TBD During PER</i>

**Criteria:** The low pressure air system shall be designed in accordance with the requirements of ANSI B31.3 for the gas systems, ASME Boiler and Pressure Vessel Code, Section VIII for the pressure vessels, and the appropriate national consensus codes for all remaining elements.

#### 1.3.1.1 Low Pressure Air Compressor System

**Definition:** The low pressure air compressor system includes all of the elements associated with the compressors. These elements include inlet air filter(s), compressor, all intercoolers (as required), all surge drums (if required), mounting frame (if required), all pressure relief valves, interstage unloading valves, aftercooler, motor, motor starter, switchgear, controls, instrumentation, data acquisition systems, and lubrication system. The low pressure air compressor system is intended to be the prime mover used to evacuate the tunnel and plenum shells to sub-atmospheric conditions as well as to provide a source of low pressure compressed air within the requirements of the overall system.

**Requirements:** The low pressure air compressor system shall utilize multiple compressor units to provide the required flow rate. The operational requirements are specified below. The specific performance requirements (e. g., number of compressors, motor sizes, number of stages, etc.) have not yet been developed. These requirements will be developed during the PER.

The low pressure air compressor system shall utilize a common manufacturer, model, and size to enhance the overall maintenance and operation of the system. Minimizing the spare parts inventory and required maintenance personnel cross-training are requirements of the system. It is intended that each of the compressors will use a similar range of flow rates and pressures (i. e., compression ratio), however, this is not yet a definitive requirement. The system components and elements (e. g., motors, bearings, valves, etc.) shall also be of uniform rating, size, and manufacturer to the fullest extent practicable.

Each of the low pressure air compressor systems shall be capable of remote starting and stopping (this includes the compressors and all of the necessary support equipment). Compressor health monitoring instrumentation shall be output to the local compressor control panel, the remote

start/stop control panel, and the facility Predictive Maintenance System. The low pressure air compressors shall be configured to minimize the time for accessing all maintenance elements. All sensors shall be easily accessible. The overall reliability of the low pressure air compressor system shall be *TBD during the PER*.

Criteria: *TBD*

#### 1.3.1.2 Low Pressure Air Drying System

Definition: The low pressure air drying system is provided to remove the moisture in the low pressure air stream. This system is located downstream of the low pressure air compressor system. Each air drier package consists of desiccant filled dryer towers and associated regeneration heater, blower, and valving and back pressure regulator which prevents inadvertent rapid blowdown of the dryers and damage or carryover of the desiccant. The dryers use an automatic regeneration circuit to minimize operator requirements. The regeneration circuit is accomplished using a heat source with an air blower. The heated air is passed through the reactivating dryer tower and either discharged to atmosphere or recirculated. All controls, valving, support structure, towers, desiccant, etc. necessary for the dryer are considered as part of this element.

Requirements: The low pressure air drying system shall utilize multiple units to match the specified flow rate. Fundamental requirements for the low pressure air drying system include a highly reliable and productive system that meets the performance requirements. The specific performance requirements (e. g., number of air drying units, number of towers per unit, type of desiccant, method of circuit regeneration, etc.) are *TBD*. *These requirements will be developed during the PER*. The climatological requirements are provided in Section 1.1.

The low pressure air drying system shall utilize a common manufacturer, model, and size to enhance the overall maintenance and operations of the system. Minimizing the spare parts inventory and required maintenance personnel cross-training are requirements of the system. It is intended that each of the air dryers will use a similar range of flow rates and pressures, however, this is not yet a definitive requirement. The system components and elements shall also be of uniform rating, size, and manufacturer to the fullest extent practicable.

Each of the low pressure air drying units shall be capable of automatically starting and stopping. Each of the low pressure air drying units shall be capable of automatically switching from drying to reactivation without any operator intervention. Each low pressure air drying unit shall be equipped with the necessary control and health monitoring instrumentation and control systems. The output from the data systems shall be routed to the local control area as well as the remote control room and also the facility Predictive Maintenance System.

The low pressure air drying units shall be configured to minimize the time for accessing all maintenance elements. All sensors shall be easily accessible.

The overall reliability of the low pressure air drying system shall be *TBD during the PER*.

**Criteria:** *TBD*

### 1.3.1.3 Low Pressure Air Storage System

**Definition:** The low pressure air storage system is used to store the low pressure compressed air for the various uses. The low pressure air storage system is used to: (1) provide for rapid recovery of the tunnel plenums after personnel entries and model configuration changes, (2) an additional air source for gross pressure changes of the tunnel circuits, (3) provide a source of makeup air as part of the tunnel pressure control system, (4) act as a buffer or accumulator between the low pressure air compressors and the end users, and (5) provide a source of air for selected model propulsion simulations. The low pressure air storage system includes the storage vessel(s), all necessary support structure, all necessary ladders etc., manways and penetrations as required by the ASME Boiler and Pressure Vessel Code, all pressure relief devices, and all monitoring instrumentation.

**Requirements:** All of the vessels used in the low pressure air storage system shall be designed, fabricated, inspected, tested, and stamped in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII. The intent is to have uniform sizes for the low pressure air storage vessels. The decision of whether the low pressure air storage field would be a centrally located storage field with distribution piping to end use points, or a distributed storage field scattered around the complex site is *TBD during the PER phase*. The performance requirements for the Low Pressure Air Storage System are provided in Table 1.3.1.3.a.

**Table 1.3.1.3.a Low Pressure Air Storage System Requirements**

Parameter	Requirement
Volume of Low Pressure Air Storage Field (cubic feet)	<i>TBD During PER</i>
Storage Vessel Type	<i>TBD During PER</i>
Storage Vessel Design Pressure (psig)	<i>TBD During PER</i>
Storage Vessel Maximum Design Temperature (°F)	<i>TBD During PER</i>
Storage Vessel Minimum Design Temperature (°F)	<i>TBD During PER</i>
Storage Vessel Material Type	<i>TBD During PER</i>
Quantity of Storage Vessels	<i>TBD During PER</i>
Inlet/Outlet Penetration Sizes (pipe size)	<i>TBD During PER</i>
Overpressure Protection Required (pps)	<i>TBD During PER</i>
Weight of Each Vessel	<i>TBD During PER</i>

**Criteria:** *TBD*

### 1.3.1.4 Low Pressure Air Distribution System

**Definition:** The low pressure air distribution system provides the means of interconnecting all of the low pressure air components to each other and to all of the end users. The low pressure air system is used for wind tunnel pressurization and evacuation, wind tunnel pressure control

(makeup air and evacuation), wind tunnel dew point control; and model propulsion simulations (in the wind tunnels, the wind tunnel model preparation rooms, and the calibration facilities).

The low pressure air distribution system connects (1) both of the wind tunnel pressure shells and plenum/test sections to the pressure shell evacuation elements (low pressure compressor suction), (2) interconnection of the low pressure compressors with the low pressure air dryers, low pressure air storage system, and the low pressure air discharge silencing system, (3) the low pressure air system compressors and air storage to both of the wind tunnel pressure shells for shell pressurization, (4) the low pressure air system compressors and air storage to the other end users (model preparation rooms and the calibration facilities), and (6) the low pressure air system compressors and air storage system to the low pressure air heating system. Other uses may be identified in the future.

The low pressure air distribution system includes the following types of elements or components typically included in air systems: valves, filters, piping, pipe supports, vent silencers, instrumentation and sensors, controllers, fittings, heat exchangers, insulation, etc..

The tunnel evacuation subsystem is used to depressurize the two wind tunnels. The depressurization can be done to reduce pressure to atmospheric conditions or to reduce the tunnel pressure to subatmospheric conditions.

**Requirements:** The low pressure air distribution system is an integrated network of piping, valves, and other components which provide the compressed air services to all of the end users. Providing the services to the end users requires an integrated plan to minimize the lengths of pipes, and to minimize the number of valves, filters, and other components in the system. The specific performance requirements (e. g., line size, design pressure, flowrate to the individual end user, component features, design temperatures, etc.) are *TBD*. *These requirements will be developed during the PER*. The end user performance requirements are provided in Table 1.3.1.4.a. The low pressure air distribution system control requirements are provided in Table 1.3.1.4.b.

The low pressure air distribution system shall allow for the operations of the two tunnels as noted in Table 1.3.1.a. The low pressure air distribution system elements shall utilize common manufacturers for similar items to enhance the overall maintenance and operation of the system. Minimizing the spare parts inventory and required maintenance personnel cross-training are requirements of the system. The low pressure air distribution system shall be configured to minimize the time for accessing all maintenance elements. All sensors, valves, filters, mechanical connections, and any other components requiring periodic maintenance shall be easily accessible through the use of permanent ladders, platforms, etc.

A centralized valve position monitoring and control system will be incorporated in order to ascertain the system configuration at any time. The low pressure air distribution system shall allow for remote operation of the system and provide an indication of valve position for all the system valves to remote location(s). All control valves and isolation valves shall be remotely controlled either through the use of push buttons and/or as part of an integrated control system.

All of the valves shall have manual operators to allow for isolation of sections of the system during periods of maintenance.

Each segment of the low pressure air distribution system shall be equipped with the necessary control and health monitoring instrumentation and control systems. The output from the data systems shall be routed to the local control area as well as the remote control room and also the facility Predictive Maintenance System.

Air filters are provided in the low pressure air distribution system to remove particulates of desiccant that may have been carried over from the dryers as well as to remove any pipe rust, scale, dirt etc. that may be in the line. The filters are arranged in banks in order to provide a degree of redundancy as well as to reduce the maintenance impact associated with changing large filter elements. The filters shall utilize a high collapse pressure rating for the elements (100% of the system design pressure) to ensure good quality elements and to prevent premature failure/collapse of the element. The filter elements shall be ultrasonically cleanable stainless steel mesh elements. The filter vessels shall be designed, fabricated, tested, inspected, and stamped in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

The low pressure air heating system is used to ensure the tunnel and plenum pressurization air is at the same temperature as the rest of the tunnel circuit when it is admitted into the tunnel. This is to prevent any thermal stratification or any other "cold spots" in the tunnel. The purpose of this system is to ensure the plenum air is at the tunnel temperature so that once tunnel flow is re-established, there is not a bubble of cold air being pushed around the circuit. The low pressure air heating system performance requirements are noted in Tables 1.3.1.4.a and 1.3.1.4.b.

The tunnel evacuation system shall be capable of depressurizing or evacuating either of the two tunnels within the time constraints noted in Table 1.3.1.a. The tunnel evacuation system shall allow for simultaneous depressurization of either of the two tunnels. In addition, the tunnel evacuation system shall be used as part of the tunnel pressure control system to allow for reducing the tunnel pressure setpoint.

The low pressure air discharge silencing system shall allow for simultaneous depressurization of either of the two tunnels. The low pressure air discharge silencing system requirements are provided in Table 1.3.1.4.c.

**Table 1.3.1.4.a Low Pressure Air Distribution System Performance Requirements**

Service	Design Press. Range (psia)	Design Temp. Range (Deg F)	Max. Flowrate (pps)
LSWT Evacuation System	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Evacuation System	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Compressor Suction Sys.	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Pressurized Air Distribution Piping	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Component Interconnection Piping	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Discharge Silencer Piping	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Pressurization and Pressure Control System	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Pressurization and Pressure Control System	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Other Users Low Pressure Supply System	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>

**Table 1.3.1.4.b Low Pressure Air Distribution System Control Requirements**

End Use Point	Controlled Parameter	Range of Control	Accuracy of Control
LSWT Pressure Shell & Plenum - Evacuation	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Pressure Shell & Plenum - Pressurization	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Pressure Shell & Plenum - Evacuation	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Pressure Shell & Plenum - Pressurization	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Model Prep. Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Model Prep. Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Plenum Air Heater	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Plenum Air Heater	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Air Calibration Laboratory	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>

**Table 1.3.1.4.c Low Pressure Air Silencing System Requirements**

Parameter	Requirement
Silencer Shell Design Pressure	<i>TBD During PER</i>
Quantities of Silencers	<i>TBD During PER</i>
Silencer Shell Design Temperature	<i>TBD During PER</i>
Silencer Flowrate	<i>TBD During PER</i>
Silencer Noise Attenuation Range/Frequency	<i>TBD During PER</i>

**Criteria:** *TBD*

### 1.3.2 High Pressure Air System

**Definition:** The high pressure air system is used to: (1) provide clean, dry compressed air for model propulsion simulations and (2) provide a backup compressed air source for the low pressure air system.

The system will be an interconnected one that allows for multitasking of components in order to reduce the overall complexity of the system while meeting the productivity requirements. The system is composed of five primary subsystems: (1) the high pressure air compressor system, (2) the high pressure air drying system, (3) the high pressure air storage system, (4) the high pressure air heating system, and (5) the high pressure air distribution system.

**Requirements:** The high pressure air system use requirements are provided in Sections 1.4 (for LSWT Model Propulsion Simulation Testing) and 1.5 (for TSWT Model Propulsion Simulation Testing). The specific operational requirements for the high pressure air system are provided in Table 1.3.2.a and the performance requirements are provided in Table 1.3.2.b.

Integrated control systems shall be provided with redundancy to accommodate any single point of failure without facility damage or personnel harm. Programmable Logic Controllers (PLC's) shall be used to the fullest extent practicable to provide interlocks, control of discrete devices, analog control loops, and a fiber digital data interface to the control room. Commands from the control room will provide coordination, initiation, and termination activities as well as process set points.

**Table 1.3.2.a High Pressure Air System Operational Requirements**

Item	Requirement
1.	Provide the capability of performing model propulsion simulations at any two end use points simultaneously without heating. This includes all elements of the system; compressors, storage volume, line sizes, etc.
2.	Provide the capability of performing model propulsion simulations at any two end use points simultaneously with heating of any specified magnitude at one of the end use points. This includes all elements of the system; compressors, storage volume, line sizes, etc.
3.	Provide the capability of performing all heated model propulsion simulations at all end use points with the exception of the High Speed Civil Transport propulsion simulations which are discussed in Section 1.3.1 above. This includes all elements of the system, compressors, storage volume, line sizes, etc.
4.	The compressor system may be designed to supply on demand and participate in facility load leveling and main drive system soft start intelligent control. <i>This is a TBD during PER if this will be done.</i>

**Table 1.3.2.b High Pressure Air System Performance Requirements**

Parameter	Requirement
Maximum Design Pressure (psig)	<i>TBD During PER</i>
Minimum Design Pressure (psig)	<i>TBD During PER</i>
Maximum Design Temperature (°F)	<i>TBD During PER</i>
Minimum Design Temperature (°F)	<i>TBD During PER</i>
Maximum Design Flowrate (pps)	<i>TBD During PER</i>
Absolute Particulate Size (i. e., filtration required - microns)	<i>TBD During PER</i>
Maximum Dewpoint at Design Pressure (°F)	<i>TBD During PER</i>
Maximum Oil Content at Design Pressure (ppm)	<i>TBD During PER</i>
Overall High Pressure Air System Reliability (%)	<i>TBD During PER</i>

**Criteria:** The high pressure air system shall be designed in accordance with the requirements of ANSI B31.3 for the gas systems, ASME Boiler and Pressure Vessel Code, Section VIII for the pressure vessels, and the appropriate national consensus codes for all remaining elements.

### 1.3.2.1 High Pressure Air Compressor System

**Definition:** The high pressure air compressor system includes all of the elements associated with the compressors. These elements include inlet air filter(s), compressors, all intercoolers (as required), all surge drums (if required), mounting frame (if required), all pressure relief valves, interstage unloading valves, aftercooler, motors, motor starters, switchgear, controls, instrumentation, data acquisition systems, and lubrication systems. The high pressure air compressor system, in conjunction with the high pressure air storage system, is intended to be the prime mover used to provide the model propulsion simulation capability.

**Requirements:** The high pressure air compressor system shall utilize multiple compressor units to provide the required flow rate. The specific performance requirements (e. g., number of compressors, motor sizes, number of stages, etc.) are *TBD*. *These requirements will be developed during the PER.*

The high pressure air compressor system shall utilize a common manufacturer, model, and size to enhance the overall maintenance and operation of the system. Minimizing the spare parts inventory and required maintenance personnel cross-training are requirements of the system. It is intended that each of the compressors will use a similar range of flow rates and pressures (i. e., compression ratio), however, this is not yet a definitive requirement. The system components and elements (e. g., motors, bearings, valves, etc.) shall also be of uniform rating, size, and manufacturer to the fullest extent practicable.

Each of the high pressure air compressors shall be capable of remote starting and stopping (this includes the compressors and all of the necessary support equipment). Compressor health monitoring instrumentation shall be output to the local compressor control panel, the remote

start/stop control panel, and the facility Predictive Maintenance System. The high pressure air compressors shall be configured to minimize the time for accessing all maintenance elements. All sensors shall be easily accessible. The overall reliability of the high pressure air compressor system shall be *TBD During the PER*.

Criteria: *TBD*

### 1.3.2.2 High Pressure Air Drying System

Definition: The high pressure air drying system is provided to remove the moisture in the high pressure air stream. This system is located downstream of the high pressure air compressor system. Each air drier package consists of desiccant filled dryer towers and associated regeneration heater, blower, and valving and back pressure regulator which prevents inadvertent rapid blowdown of the dryers and damage or carryover of the desiccant. The dryers use an automatic regeneration circuit to minimize operator requirements. The regeneration activity will be accomplished using a heat source with an air blower. The heated air is passed through the reactivating dryer tower and either discharged to atmosphere or recirculated. All controls, valving, support structure, towers, desiccant, etc. necessary for the dryer are considered as part of this element.

Requirements: The high pressure air drying system shall utilize multiple units to match the specified flow rate. The specific performance requirements (e. g., number of air drying units, number of towers per unit, type of desiccant, method of circuit regeneration, etc.) are *TBD*. These requirements will be developed during the PER. The climatological requirements are provided in Section 1.1.

The high pressure air drying system shall utilize a common manufacturer, model, and size to enhance the overall maintenance and operations of the system. Minimizing the spare parts inventory and required maintenance personnel cross-training are requirements of the system. It is intended that each of the air dryers will use a similar range of flow rates and pressures, however, this is not yet a definitive requirement. The system components and elements shall also be of uniform rating, size, and manufacturer to the fullest extent practicable.

Each of the high pressure air drying units shall be capable of automatically starting and stopping. Each of the high pressure air drying units shall be capable of automatically switching from drying to reactivation without any operator intervention. Each high pressure air drying unit shall be equipped with the necessary control and health monitoring instrumentation and control systems. The output from the data systems shall be routed to the local control area as well as the remote control room and also the facility Predictive Maintenance System.

The high pressure air drying units shall be configured to minimize the time for accessing all maintenance elements. All sensors shall be easily accessible.

The overall reliability of the high pressure air drying system shall be *TBD During the PER*.

Criteria: *TBD*

### 1.3.2.3 High Pressure Air Storage System

**Definition:** The high pressure air storage system is used to store the high pressure compressed air for the model propulsion simulations. The high pressure air storage system includes the storage vessel(s), all necessary support structure, all necessary ladders etc., manways and penetrations as required by the ASME Boiler and Pressure Vessel Code, all pressure relief devices, and all monitoring instrumentation.

**Requirements:** All of the vessels used in the high pressure air storage system will be designed, fabricated, inspected, tested, and stamped in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII. The intent is to have uniform sizes for the high pressure air storage vessels. The decision of whether the high pressure air storage field would be a centrally located storage field with distribution piping to end use points, or a distributed storage field scattered around the complex site is *TBD during the PER phase*. The performance requirements for the High Pressure Air Storage System are provided in Table 1.3.2.3.a.

**Table 1.3.2.3.a High Pressure Air Storage System Requirements**

Parameter	Requirement
Volume of High Pressure Air Storage Required (cubic feet)	<i>TBD During PER</i>
Storage Vessel Type	<i>TBD During PER</i>
Storage Vessel Design Pressure (psig)	<i>TBD During PER</i>
Storage Vessel Maximum Design Temperature (Deg F)	<i>TBD During PER</i>
Storage Vessel Minimum Design Temperature (Deg F)	<i>TBD During PER</i>
Storage Vessel Material Type	<i>TBD During PER</i>
Quantity of Storage Vessels	<i>TBD During PER</i>
Inlet/Outlet Penetration Sizes (pipe size)	<i>TBD During PER</i>
Overpressure Protection Required (pps)	<i>TBD During PER</i>
Weight of Each Vessel	<i>TBD During PER</i>

**Criteria:** *TBD*

### 1.3.2.4 High Pressure Air Heating System

**Definition:** The high pressure air heating system provides the means of elevating the high pressure air temperature to the levels required by the various types of end users. The heating system includes the heating method, the connections into the high pressure air distribution system, isolation valves, overpressure protection of all elements, the source of heating to a definitive point (based upon the method selected), filters, instrumentation, all control elements and systems, data output to the facility remote control operators station and Predictive Maintenance Systems, and the distribution piping from the heat source to the end use points. Note that the *use of dedicated heated high pressure air distribution system lines is TBD during the PER.*

**Requirements:** The high pressure air heating system is an integrated network of piping, valving, and other components which provide the heated compressed air services to all of the end users. Providing the services to the end users requires an integrated plan to minimize the lengths of pipes, and to minimize the number of valves, filters, heat exchangers and other components in the system. Selection of the appropriate means of heating the high pressure air is *TBD during the PER*. The specific performance requirements (e. g., line size, design pressure, flowrate to the individual end user, component features, design temperatures, etc.) are *TBD*. *These requirements will be developed during the PER*. The high pressure air heating system will provide control of the flow, or pressure, or temperature at a given end use point. The nature of the controlled element at each end use point will be *determined during the PER*.

The high pressure air heating system elements shall utilize common manufacturers for similar items to enhance the overall maintenance and operation of the system. Minimizing the spare parts inventory and required maintenance personnel cross-training are requirements of the system. The high pressure air heating system shall be configured to minimize the time for accessing all maintenance elements. All sensors, valves, filters, mechanical connections, and any other components requiring periodic maintenance shall be easily accessible through the use of permanent ladders, platforms, etc.

A centralized valve position monitoring and control system will be incorporated in order to ascertain the system configuration at any time. The high pressure air heating system shall allow for remote operation of the system and provide an indication of valve position for all the system valves to remote location(s). All control valves and isolation valves shall be remotely controlled either through the use of push buttons and/or as part of an integrated control system. All of the valves shall have manual operators to allow for isolation of sections of the system during periods of maintenance. The high pressure air heaters shall be configured to accept a remote setpoint input. The high pressure air heating system shall be capable of automatic and remote operation.

Each segment of the high pressure air heating system shall be equipped with the necessary control and health monitoring instrumentation and control systems. The output from the data systems shall be routed to the local control area as well as the remote control room and also the facility Predictive Maintenance System.

**Criteria:** *TBD*

### 1.3.2.5 High Pressure Air Distribution System

**Definition:** The high pressure air distribution system provides the means of distributing the high pressure air (model propulsion simulation air) to all of the end users. The uses of the high pressure air system include both of the wind tunnels for model propulsion simulations, both of the model preparation rooms that utilize propulsion simulation capability; the air calibration laboratory where propulsion simulation devices are calibrated; the interconnections of the high pressure air system systems (compressor system, dryer system, discharge silencing system, and air storage system); and the high pressure air heating subsystem that is used for heated model propulsion simulations. Other uses may be identified in the future. The high pressure air distribution system includes the following types of elements or components typically included in

air systems: valves, filters, piping, pipe supports, vent silencers, instrumentation and sensors, controllers, fittings, heat exchangers, insulation, etc..

**Requirements:** The high pressure air distribution system is an integrated network of piping, valving, and other components which provide the model propulsion simulation air services to all of the end users. Providing the services to the end users requires an integrated plan to minimize the lengths of pipes, and to minimize the number of valves, filters, and other components in the system. The specific performance requirements (e. g., line size, design pressure, flowrate to the individual , component features, design temperatures, etc.) are *TBD*. *These requirements will be developed during the PER*. The end user performance requirements are provided in Table 1.3.2.5.a. The high pressure air distribution system control requirements are provided in Table 1.3.2.5.b.

The high pressure air distribution system elements shall utilize common manufacturers for similar items to enhance the overall maintenance and operation of the system. Minimizing the spare parts inventory and required maintenance personnel cross-training are requirements of the system. The high pressure air distribution system shall be configured to minimize the time for accessing all maintenance elements. All sensors, valves, filters, mechanical connections, and any other components requiring periodic maintenance shall be easily accessible through the use of permanent ladders, platforms, etc.

A centralized valve position monitoring and control system will be incorporated in order to ascertain the system configuration at any time. The high pressure air distribution system shall allow for remote operation of the system and provide an indication of valve position for all the system valves to remote location(s). All control valves and isolation valves shall be remotely controlled either through the use of push buttons and/or as part of an integrated control system. All of the valves shall have manual operators to allow for isolation of sections of the system during periods of maintenance.

Air filters are provided in the high pressure air distribution system to remove particulates of desiccant that may have been carried over from the dryers as well as to remove any pipe rust, scale, dirt etc. that may be in the line. The filters are arranged in banks in order to provide a degree of redundancy as well as to reduce the maintenance impact associated with changing large filter elements. The filters shall utilize a high collapse pressure rating for the elements (100% of the system design pressure) to ensure good quality elements and to prevent premature failure/collapse of the element. The filter elements shall be ultrasonically cleanable stainless steel mesh elements. The filter vessels shall be designed, fabricated, tested, inspected, and stamped in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

Each segment of the high pressure air distribution system shall be equipped with the necessary control and health monitoring instrumentation and control systems. The output from the data systems shall be routed to the local control area as well as the remote control room and also the facility Predictive Maintenance System.

The high pressure air discharge silencing system shall allow for simultaneous discharge from any two end use points. The discharge silencer performance requirements are provided in Table 1.3.2.5.c.

**Table 1.3.2.5.a High Pressure Air Distribution System Performance Requirements**

Service	Design Press. Range (psia)	Design Temp. Range (°F)	Max. Flowrate (pps)
LSWT Plenum	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Plenum	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Model Prep. Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Model Prep. Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Component Interconnect Piping	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Discharge Silencer Piping	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Air Calibration Laboratory	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
To High Pressure Air Heating	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Other Users High Pressure Air System	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>

**Table 1.3.2.5.b High Pressure Air Distribution System Control Requirements**

End Use Point	Controlled Parameter	Range of Control	Accuracy of Control
LSWT Pressure Shell & Plenum	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Pressure Shell&Plenum	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Model Prep. Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Model Prep. Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Air Calibration Laboratory	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>

**Table 1.3.2.5.c High Pressure Air Silencing System Requirements**

Parameter	Requirement
Silencer Shell Design Pressure	<i>TBD During PER</i>
Quantities of Silencers	<i>TBD During PER</i>
Silencer Shell Design Temperature	<i>TBD During PER</i>
Silencer Flowrate	<i>TBD During PER</i>
Silencer Noise Attenuation Range/Frequency	<i>TBD During PER</i>

**Criteria:** *TBD*

### 1.3.3 Vacuum System

**Definition:** The vacuum system is used to reduce the pressures of either of the two tunnels to the final sub-atmospheric test condition and also for pressure control (primarily vacuum). The vacuum system consists of three subsystems: (1) the vacuum pumps, (2) the vacuum storage, and (3) the vacuum distribution system (which includes the suction lines from the tunnels, the

vacuum storage, and all other users, a cross-connect to the low pressure air compressor suction system, and the vacuum discharge to atmosphere). The necessary controls, sensors, and data acquisition elements and subsystems are included with the appropriate subsystem.

**Requirements:** The vacuum system operational requirements are provided in Table 1.3.3.a and the performance requirements are provided in Table 1.3.3.b.

Integrated control systems shall be provided with redundancy to accommodate any single point of failure without facility damage or personnel harm. Programmable Logic Controllers (PLC's) shall be used to the fullest extent practicable to provide interlocks, control of discrete devices, analog control loops, and a fiber digital data interface to the control room. Commands from the control room will provide coordination, initiation, and termination activities as well as process set points.

**Table 1.3.3.a Vacuum System Operational Requirements**

Item	Requirement
1.	Provide sufficient flow and capacity to evacuate the LSWT Pressure shell from <b>TBD atms. to TBD atms. within TBD min.</b> without providing simultaneous evacuation for the TSWT or any other user. This is for the final pressure reduction (if required).
2.	Provide sufficient flow and capacity to evacuate the TSWT Pressure shell from <b>TBD atms. to TBD atms. within TBD min.</b> without providing simultaneous evacuation for the TSWT or any other user. This is for the final pressure reduction (if required).
3.	Provide sufficient flow and capacity to evacuate the plenum in either the LSWT or the TSWT to the pressure levels specified in Sections 1.4 or 1.5 respectively, in <b>TBD min.</b>
4.	Provide capability of simultaneous or individual tunnel pressure control for either tunnel. The system may need to be interfaced with the low pressure air distribution system (Section 1.3.1.6) to provide positive pressure control. The vacuum system shall be capable of maintaining the tunnel pressure within <b>TBD psi.</b>
5.	Provide sufficient vacuum storage capacity to allow for <b>TBD.</b>

**Table 1.3.3.b Vacuum System Performance Requirements**

Parameter	Requirement
Maximum Design Pressure (psia)	<b>TBD During PER</b>
Minimum Design Pressure (psia)	<b>TBD During PER</b>
Maximum Design Temperature (°F)	<b>TBD During PER</b>
Minimum Design Temperature (°F)	<b>TBD During PER</b>
Maximum Design Flowrate (pps)	<b>TBD During PER</b>
Absolute Particulate Size (i. e., filtration required - microns)	<b>TBD During PER</b>
Maximum Dewpoint at Design Pressure (°F)	<b>TBD During PER</b>
Maximum Oil Content at Design Pressure (ppm)	<b>TBD During PER</b>
Overall Vacuum System Reliability (%)	<b>TBD During PER</b>

**Criteria:** The vacuum system shall be designed in accordance with the requirements of ANSI B31.3 for the gas systems, ASME Boiler and Pressure Vessel Code, Section VIII for the pressure vessels, and the appropriate national consensus codes for all remaining elements.

### 1.3.3.1 Vacuum Pump System

**Definition:** The vacuum pump system includes all of the elements associated with the vacuum pumps. These elements include inlet air filter(s), vacuum pump(s), all intercoolers (as required), all surge drums (if required), mounting frame (if required), all pressure relief valves, interstage unloading valves, aftercooler, motor, motor starter, switchgear, controls, instrumentation, data acquisition systems, and lubrication system.

**Requirements:** The vacuum pump system will utilize multiple pumps to provide the required flow rate based upon the specified uses. The specific performance requirements (e. g., number of vacuum pumps, motor sizes, number of stages, etc.) are *TBD*. *These requirements will be developed during the PER.*

The vacuum pump system shall utilize a common manufacturer, model, and size to enhance the overall maintenance and operation of the system. Minimizing the spare parts inventory and required maintenance personnel cross-training are requirements of the system. It is intended that each of the vacuum pumps will use a similar range of flow rates and pressures (i. e., compression ratio). The system components and elements (e. g., motors, bearings, valves, etc.) shall also be of uniform rating, size, and manufacturer to the fullest extent practicable.

Each of the vacuum pumps shall be capable of remote starting and stopping (this includes the vacuum pumps and all of the associated support equipment). Vacuum pump health monitoring instrumentation shall be output to the local vacuum pump control panel, the remote start/stop control panel, and the facility Predictive Maintenance System.

The vacuum pumps shall be configured to minimize the time for accessing all maintenance elements. All sensors shall be easily accessible.

The overall reliability of the vacuum pump system shall be *TBD during the PER*.

**Criteria:** *TBD*

### 1.3.3.2 Vacuum Storage System

**Definition:** The vacuum storage system is used to help ensure a ready supply of vacuum to aid in rapid evacuation of the LSWT and TSWT plenums during subatmospheric testing. Other uses of the vacuum storage system are to provide a ready source of vacuum for other users as required. The vacuum storage system includes the vessels, the necessary support structure, appropriate manways and ladders, and all penetrations for instrumentation, process connections, etc.

**Requirements:** All of the vessels used in the vacuum storage system shall be designed, fabricated, inspected, tested, and stamped in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII. The intent is to have a uniform size for the storage vessels. The decision of whether the vacuum storage field would be a centrally located storage field with distribution piping to end use points, or a distributed storage field scattered around the complex site is *TBD during the PER phase*. The performance requirements for the Vacuum Storage System are provided in Table 1.3.3.2.a.

**Table 1.3.3.2.a Vacuum Storage System Requirements**

Parameter	Requirement
Volume of Vacuum Storage Required (cubic feet)	<i>TBD During PER</i>
Storage Vessel Type	<i>TBD During PER</i>
Storage Vessel Internal Design Pressure (psia)	<i>TBD During PER</i>
Storage Vessel External Design Pressure (psia)	<i>TBD During PER</i>
Storage Vessel Maximum Design Temperature (°F)	<i>TBD During PER</i>
Storage Vessel Minimum Design Temperature (°F)	<i>TBD During PER</i>
Storage Vessel Material Type	<i>TBD During PER</i>
Quantity of Storage Vessels	<i>TBD During PER</i>
Overpressure Protection Required (pps)	<i>TBD During PER</i>
Inlet/Outlet Penetration Sizes (pipe size)	<i>TBD During PER</i>
Weight of Each Vessel	<i>TBD During PER</i>

**Criteria:** *TBD*

### 1.3.3.3 Vacuum Distribution System

**Definition:** The vacuum distribution system is the interconnecting piping, valves, etc. that is used to connect all of the vacuum system elements to each other as well as to the rest of the complex's systems. The vacuum distribution system includes the connecting piping from the two wind tunnels to the vacuum pumps, the connecting piping from the vacuum storage to the vacuum pumps, the connecting piping from all other users to the vacuum pumps or storage, cross-connect piping to the low pressure air compressor suction system, and the discharge from the vacuum pump(s) to atmosphere. The vacuum distribution system includes the following types of elements or components: valves, filters, piping, pipe supports, instrumentation and sensors, controllers, fittings, insulation, etc..

**Requirements:** The vacuum distribution system is an integrated network of piping, valving, and components to provide the vacuum services to all of the users. Providing the services to the end users requires an integrated plan to minimize the lengths of pipes, and to minimize the number of valves, filters, and other components in the system. The specific performance requirements (e. g., line size, design pressure, flowrate to the individual end user, component features, design temperatures, etc.) are *TBD*. *These requirements will be developed during the PER*. The end user performance requirements are provided in Table 1.3.3.3.a. The vacuum system control requirements are provided in Table 1.3.3.3.b.

The vacuum distribution system elements shall utilize common manufacturers for similar items to enhance the overall maintenance and operations of the system. Minimizing the spare parts inventory and required maintenance personnel cross-training are requirements of the system. The vacuum distribution system shall be configured to minimize the time for accessing all maintenance elements. All sensors, valves, filters, mechanical connections, and any other components requiring periodic maintenance shall be easily accessible through the use of permanent ladders, platforms, etc.

A centralized valve position monitoring and control system will be incorporated in order to ascertain the system configuration at any time. The vacuum distribution system shall allow for remote operation of the system and provide an indication of valve position for all the system valves to remote location(s). All control valves and isolation valves shall be remotely controlled either through the use of push buttons and/or as part of an integrated control system. All of the valves shall have manual operators to allow for isolation of sections of the system during periods of maintenance.

Air filters are provided in the vacuum distribution system to remove particulates any pipe rust, scale, dirt etc. that may be in the line in order to protect the vacuum pump(s). The filters are arranged in banks in order to provide a degree of redundancy as well as to reduce the maintenance impact associated with changing large filter elements. The filters shall utilize a high collapse pressure rating for the elements (100% of the system design pressure) to ensure good quality elements and to prevent premature failure/collapse of the element. The filter elements shall be ultrasonically cleanable elements. The filters shall be designed, fabricated, tested, inspected, and stamped in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

Each segment of the vacuum distribution system shall be equipped with the necessary control and health monitoring instrumentation and control systems. The output from the data systems shall be routed to the local control area as well as the remote control room and also the facility Predictive Maintenance System.

**Table 1.3.3.3.a Vacuum Distribution System Operational Requirements**

Service	Design Press. Range (psia)	Design Temp. Range (Deg F)	Max. Flowrate (pps)
LSWT Plenum/Shell	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Plenum/Shell	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Model Preparation Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Model Preparation Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Component Interconnect Piping	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Discharge Silencer Piping	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Air Calibration Laboratory	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Other Vacuum Users	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>

Table 1.3.3.3.b Vacuum Distribution System Control Requirements

End Use Point	Controlled Parameter	Range of Control	Accuracy of Control
LSWT Pressure Shell & Plenum	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Pressure Shell & Plenum	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Model Prep. Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Model Prep. Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Air Calibration Laboratory	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>

**Criteria:** *TBD*

### 1.3.4 Cooling System

**Definition:** The cooling system is a centralized evaporative cooling system which supports low temperature rise waste heat exchangers in each of the two wind tunnels and the auxiliary support systems. The cooling system consists of three primary subsystems: (1) the cooling tower(s), (2) the cooling water distribution pumps, and (3) the cooling water distribution system. All of the necessary controls, sensors, and data acquisition elements and subsystems are included with the appropriate subsystems. The cooling system includes the cooling system components, all starters for all cooling equipment motors, and switchgear for the cooling system, as well as all controls, predictive maintenance elements, and instrumentation required. The cooling system serves the entire complex and is considered to be part of the cooling system up to either a specific heat exchanger or to a specific distribution manifold in the case of the two wind tunnel heat exchangers.

**Requirements:** The cooling system operating requirements are specified in Table 1.3.4.a and the performance requirements are specified in Table 1.3.4.b. The system shall be an energy efficient interconnected system that allows for multi-tasking of components in order to reduce the overall complexity of the system while meeting the productivity requirements. Integrated controls systems

shall be provided with redundancy to accommodate any single point of failure without facility damage or personnel harm. Programmable Logic Controllers (PLC's) shall be used to the fullest extent practicable to provide interlocks, control of discrete devices, analog control loops, and a fiber digital data interface to the control room. Commands from the control room shall provide coordination, initiation, and termination activities as well as process set points.

Table 1.3.4.a Cooling System Operating Requirements

Item	Requirement
1.	<b>Peak Demand Operation on 1% Exceedance Value Day (Summer).</b> The following components and systems be operating and all components and systems will remain within their specified maximum temperature limitations: <ol style="list-style-type: none"> <li>1. LSWT at maximum power</li> <li>2. Hot Model Propulsion simulation in the LSWT</li> <li>3. TSWT at maximum power</li> <li>4. Either: All low pressure air compressors operating at maximum power, or All compressors required for the maximum model propulsion simulation flowrate be operating at maximum power,</li> <li>5. All other ancillary components that are required for the proper operation of the components noted above are operating</li> </ol>
2.	Separate operation of either the LSWT or the TSWT.

Table 1.3.4.b Cooling System Performance Requirements

Parameter	Requirement
Maximum Design Pressure (psig)	<i>TBD During PER</i>
Minimum Design Pressure (psig)	<i>TBD During PER</i>
Maximum Design Temperature (°F)	<i>TBD During PER</i>
Minimum Design Temperature (°F)	<i>TBD During PER</i>
Maximum Design Flowrate (gpm)	<i>TBD During PER</i>
Absolute Particulate Size (i. e., filtration required - microns)	<i>TBD During PER</i>
Overall Cooling System Reliability (%)	<i>TBD During PER</i>
Site Weather Conditions (temperatures)	See Section 1.1
Energy to be Removed Continuously (BTU/hr)	<i>TBD During PER</i>

#### 1.3.4.1 Cooling Tower

**Definition:** The cooling tower is used to reject the waste heat from the two tunnels, the auxiliary process systems equipment, and other ancillary equipment to the environment. The cooling tower includes the tower itself, the tower fill, the basin, the means of inducing air movement through the tower, all necessary support structures, any internal water distribution systems throughout the tower, the electrical power, controls, and data acquisition systems and components used for the tower, and any chemical addition systems.

**Requirements:** The cooling tower will be an evaporative type tower. The tower and all structures will be set on a separate sealed basin foundation. The height of the cooling tower is dependent on its location relative to nearby buildings and other site features. The height of the cooling tower will be sufficient to minimize air flow blockage and effects of fog plume. A method to control the growth of algae will be incorporated. The tower will utilize makeup water to account for evaporative and windage losses. The specific performance requirements (e. g.,

quantity of cooling towers, site location, size of cooling tower, methods of rejecting the heat, etc.) are *TBD*. *These requirements will be developed during the PER.*

A centralized cooling tower monitoring and control system will be incorporated in order to ascertain the tower configuration and performance at any time. The cooling tower shall allow for remote operation of the system. The output from the data systems shall be routed to the local control area as well as the remote control room and also the facility Predictive Maintenance System.

Criteria:        *TBD*

#### **.3.4.2 Cooling Water Distribution Pumps**

Definition: The cooling water distribution pumping system is used to provide the necessary potential energy to the cooling water system to allow it to circulate to all of the end users. The cooling water distribution pumping system is composed of the cooling water pumps and motors, support structure, all associated suction and discharge valves, motor control centers, starters, switchgear, all necessary instrumentation and control elements.

Requirements: The cooling water pump system shall utilize multiple pump units to provide the required flow rate. The specific performance requirements (e. g., quantity of cooling water pumps, total required design flow, design head per pump, motor size per pump, etc.) are *TBD*. *These requirements will be developed during the PER.*

The cooling water pump system shall utilize a common manufacturer, model, and size to enhance the overall maintenance and operation of the system. Minimizing the spare parts inventory and required maintenance personnel cross-training are requirements of the system. It is intended that each of the pumps will use a similar range of flow rates and pressures, however, this is not yet a definitive requirement. The system components and elements (e. g., motors, bearings, valves, etc.) shall also be of uniform rating, size, and manufacturer to the fullest extent practicable.

Each of the cooling water pumps shall be capable of remote operation. Pump health monitoring instrumentation shall be output to the local pump control panel, the remote start/stop control panel, and the facility Predictive Maintenance System. The cooling water pumps shall be configured to minimize the time for accessing all maintenance elements. All sensors shall be easily accessible. The overall reliability of the cooling water pump system shall be *TBD during the PER.*

Criteria:        *TBD*

#### **1.3.4.3 Cooling Water Distribution System**

Definition: The cooling water distribution system is used to transport the cooling media from the cooling tower to the respective elements requiring cooling and back to the cooling tower. The cooling water distribution system includes all piping, mains, laterals, valves, fittings, gages,

instrumentation, controls, and data acquisition elements for a complete system. The cooling water system serves the following elements: (1) LSWT heat sources (including the tunnel heat exchanger, drive motor heat exchanger, and lubrication system heat exchanger(s)); (2) TSWT heat sources (including tunnel heat exchanger, drive motor(s) heat exchangers, and lubrication system heat exchangers; (3) low pressure air compressors, high pressure air compressors, and the vacuum pumps; and (4) all other miscellaneous users.

**Requirements:** The cooling water distribution system is an integrated network of piping, valving, and other components which provide the cooling water services to all of the end users. Providing the services to the end users requires an integrated plan to minimize the lengths of pipes, and to minimize the number of valves, filters, and other components in the system.

The specific performance requirements (e. g., line size, design pressure, flowrate to the individual end user, component features, design temperatures, etc.) are *TBD*. *These requirements will be developed during the PER*. The end user performance requirements are provided in Table 1.3.4.3.a. The cooling water system control requirements are provided in Table 1.3.4.3.b.

The cooling water distribution system shall allow for operation as specified in Table 1.3.4.a. The cooling water distribution system elements shall utilize common manufacturers for similar items to enhance the overall maintenance and operation of the system. Minimizing the spare parts inventory and required maintenance personnel cross-training are requirements of the system. The cooling water distribution system shall be configured to minimize the time for accessing all maintenance elements. All sensors, valves, filters, mechanical connections, and any other components requiring periodic maintenance shall be easily accessible through the use of permanent ladders, platforms, manholes, etc.

A centralized valve position monitoring and control system will be incorporated in order to ascertain the system configuration at any time. The cooling water distribution system shall allow for remote operation of the system and provide an indication of valve position for all the system valves to remote location(s). All control valves and isolation valves shall be remotely controlled either through the use of push buttons and/or as part of an integrated control system. All of the valves shall have manual operators to allow for isolation of sections of the system during periods of maintenance.

Filters are provided in the cooling water distribution system to remove particulates as well as to remove any pipe rust, scale, dirt etc. that may be in the line. The filters are arranged in banks in order to provide a degree of redundancy as well as to reduce the maintenance impact associated with changing large filter elements. The filters shall utilize a high collapse pressure rating for the elements (100% of the system design pressure) to ensure good quality elements and to prevent premature failure/collapse of the element. The filter elements shall be ultrasonically cleanable metal elements. The filters shall be designed, fabricated, tested, inspected, and stamped in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, if appropriate.

Each segment of the cooling water distribution system shall be equipped with the necessary control and health monitoring instrumentation and control systems. The output from the data systems shall be routed to the local control area as well as the remote control room and also the facility Predictive Maintenance System.

**Table 1.3.4.3.a Cooling Water Distribution System**

<b>Service</b>	<b>Design Press. Range (psia)</b>	<b>Design Temp. Range (°F)</b>	<b>Max. Flowrate (gpm)</b>
Main Cooling Water Supply and Return Header	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Cooling Water Supply and Return	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Cooling Water Supply and Return	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Compressor Cooling Water Supply and Return	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Miscellaneous Cooling Water Supply and Return	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>

**Table 1.3.4.3.b Cooling Water Distribution System Control Requirements**

<b>End Use Point</b>	<b>Controlled Parameter</b>	<b>Range of Control</b>	<b>Accuracy of Control</b>
LSWT Heat Exchanger	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Drive Motor Heat Exchanger	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Lubrication Heat Exchanger	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Heat Exchanger	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Drive Motor(s) Heat Exchanger(s)	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Lubrication Heat EXchanger	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
LSWT Model Prep. Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
TSWT Model Prep. Room	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Air Calibration Laboratory	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>
Other End Users	<i>TBD During PER</i>	<i>TBD During PER</i>	<i>TBD During PER</i>

**Criteria:** *TBD*

### 1.3.5 Calibration Systems

**Definition:** The site shall have the capability to systematically functionally check and calibrate, as required, in a hierarchical manner beginning with each functional component and proceeding to each subsystem assembly and final complete system/facility calibration, the following types of elements: (1) air flow elements such as blowing nacelles, engine simulation nozzles, and turbine powered simulators, (2) strain-gage balances and force transducers and the equipment for calibration of hinge-moment, wing bending, fin load, etc., gages, (3) test models by performing modal analyses, and (4) all calibration, measurement, and control instrumentation. Performance and uncertainty standards shall be contained in the individual component/system specifications.

**Requirements:** The calibration capabilities required are described below.

#### 1.3.5.1 Air Flow Calibration Laboratory

**Definition:** The Airflow Calibration Laboratory shall house the equipment and capability to calibrate blowing nacelles, engine simulation nozzles, turbine powered simulators, and inlet ducts for mass flow, thrust, and drag at conditions duplicating the static pressure environment of the tunnels. The elements described above will be provided the propulsive air through either the low pressure air system (Section 1.3.1) or by the high pressure air system (Section 1.3.2). Appropriate support from the site vacuum system (Section 1.3.3) and the site cooling water system (Section 1.3.4) shall be provided. The Airflow Calibration Laboratory shall also include the appropriate instrumentation, data acquisition, and control computing elements. External connections to the appropriate site data networks shall be provided. The prime calibration device within the Air Flow Calibration Laboratory is the Air Flow Calibration Chamber.

**Requirements:** The Air Flow Calibration Laboratory shall contain instrumentation and data reduction equipment to completely calibrate each device and process the calibration data to produce a calibration algorithm for each device. The data process computer shall be connected by Local Area Network (LAN) to the tunnel data reduction computer in order to electronically download the calibration algorithm.

The Air Flow calibration chamber shall be designed for pressures over the ranges of either wind tunnel as specified in Sections 1.4 and 1.5. The Air Flow Calibration Chamber shall be designed, fabricated, tested, inspected, and stamped in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII. The Air Flow Calibration Chamber shall contain airflow and force measurement systems. The Air Flow Calibration Chamber shall be sized to accommodate the following items: (1) blowing nacelles, engine simulation nozzles, turbine powered simulators, and inlet ducts, (2) the necessary support structure and mounting hardware for these components, (3) six component balances, (4) high pressure air piping to the device being calibrated, and (5) pitching moment counter-balance, and force isolation bellows for the device under test. The Air Flow Calibration Chamber shall provide a means to isolate the inlet flow from the inlet-plus-jet/turbine flow.

The upstream portion of the chamber shall contain penetrations and flow conditioning screens to provide inlet flow to the test devices. *The required flow quality is TBD during Final Design.* A

second bulkhead shall contain calibrated venturis sized in geometric progression to accommodate the mass flow range requirement. The purpose of the calibrated venturis is *TBD*. *The sizes of the required venturis is TBD during Final Design..* Flow conditioning devices are contained between the two bulkheads to provide undisturbed flow entering the venturis. *The required flow quality entering the venturis is TBD during Final Design..* Two airflow regulation systems are required. The first supplies relatively low pressure, ambient temperature air to provide inlet flow to the device being calibrated (TPS, inlets, etc.). The second regulates the high pressure, heated air which drives the TPS turbines, supplies the blowing nacelles, or supplies the engine simulation nozzles. The required flowrates, pressures, temperatures, etc. shall be the model propulsion requirements provided in Sections 1.4 and 1.5.

The Air Flow Calibration Chamber will be pressurized to match test conditions of either wind tunnel. The source of air for the pressurization of the chamber will be *TBD during the final design..* Air is also used to provide the motive force for the test article. The test article air supply will be the high pressure air system (Section 1.3.2). The test article air supply system shall incorporate variable exit areas and flow conditioning screens. A third condition must be attained in the Air Flow Calibration Chamber, and that is a low pressure region at the discharge end of the test article. The means of providing the low pressure region and the level of the low pressure will be *TBD during the final design.*

The test article will be mounted, by a common flange, to a model support frame, which is, in turn, mounted to a pair of balances. The balances will be stiff in the normal force direction, to support the model's weight, but relatively weak in axial force to allow for precise measurement of drag and thrust. All air will be transferred across metric breaks with bellows arrangements. The entire balance mount and compensation bellows assembly will be contained in the pressure vessel, with access doors and windows included in the facility. The pressure vessel will have at least one large flange joint (equal to the major diameter of the vessel) at or near the model mounting location, to allow for model installation and removal of the model mount and compensation assembly for servicing. In the event of a turbine powered simulator failure, the pressure vessel may experience a rise in internal pressure and will, therefore, include appropriate overpressure protective devices.

Criteria:        *TBD*

### 1.3.5.2 Balance Calibration Laboratory

**Definition:** The Balance Calibration Laboratory will provide the equipment necessary to accurately calibrate all strain-gage balances and force transducers that will be used in the LSWT and the TSWT. In addition, the Balance Calibration Laboratory shall also accommodate and contain the equipment for calibration of hinge-moment, wing bending, fin load, etc., gages. It is intended that the primary calibration of the external balances be accomplished in the carts at infrequent intervals, but the balances will be provided with automatic check-calibrate load cells for daily calibration verification. The external balance load cells shall be calibrated in the Balance Calibration Laboratory or by a certified outside meteorological lab. Balance Calibration Laboratory hardware includes two automatic calibration machines, two manual calibration stands, and associated support hardware.

**Requirements:** The Balance Calibration Laboratory will provide the capability of calibration for large and small internal balances as well large and small external balances. The internal balance automatic calibration machine requirements are provided in Table 1.3.5.2.a.

**Table 1.3.5.2.a Internal Balance Calibration Machine Requirements**

Balance Type	Load Range	Accuracy	Repeatability	Calibration Time
Large	110% of Maximum Model Load Specified in Sections 1.4 and 1.5(except for Semi-Span testing)	$\pm 0.1\%$ of Maximum Load	$\pm 0.1\%$ of Maximum Load	< 8 hours for 1000 combined loadings
Small	25% of Maximum Model Load Specified in Sections 1.4 and 1.5(except for Semi-Span testing)	$\pm 0.1\%$ of Maximum Load	$\pm 0.1\%$ of Maximum Load	< 8 hours for 1000 combined loadings

In addition to the automatic calibration machines for the internal balances, the capability to manually calibrate the internal balances through the use of dead weight stands shall be provided. The manual calibration stands shall also be capable of calibrating the external balances. The requirements for the manual calibration stands are provided in Table 1.3.5.2.b.

**Table 1.3.5.2.b Manual Stand Balance Calibration Requirements**

Stand Size	Load Range	Accuracy	Repeatability
Large	110% of Maximum Model Load Specified in Sections 1.4 and 1.5 for Semi-Span testing	$\pm 0.1\%$ of Maximum Load	$\pm 0.1\%$ of Maximum Load
Small	The same range as the large internal balance automatic calibration machine	$\pm 0.1\%$ of Maximum Load	$\pm 0.1\%$ of Maximum Load

The following associated support hardware shall be provided as part of the Balance Calibration Laboratory: calibration fixtures, adapters, thermal test equipment, overhead crane, forklift, signal conditioning and data systems, actuators, hangers, levels, inclinometers, optical alignment equipment, hand tools, ring and plug gages, taper gages, surface table, dial indicators, verniers, gage blocks, microscope, and storage cabinets.

**Criteria:** TBD

### 1.3.5.3 Structural Calibration Laboratory

**Definition:** This laboratory will contain necessary equipment to support modal analysis of test models in the assembly bays.

**Requirements:** *TBD*

**Criteria:** *TBD*

### 1.3.5.4 Instrument Calibration Laboratory

**Definition:** This facility will provide the service, repair, and calibration support for measurement and control instrumentation utilized at the NWTC. The calibration services shall include the disciplines of force, force balance, strain, pressure, anemometry, skin friction, acceleration, vibration, temperature, infra-red, humidity, acoustics, dimensional, voltage, current, resistance, capacitance, frequency and time. Repair services for the majority of the electronic and physical instruments required in these facilities shall be accomplished in this laboratory.

**Requirements:** This Instrument Calibration Laboratory shall be automated to the maximum extent possible ranging from control of the calibration standards and acquisition and analysis of the instrument data to electronic transfer of all instrument calibration to the major computer used to analyze the wind tunnel data and to operate the facilities. This laboratory shall function such that the measurement uncertainty of all wind tunnel measurements shall have traceability to accepted national standards or procedures and conform to requirements of national calibration laboratory documentation such as MIL-STD-4566A and the International Standards Organization 9000 series.

**Criteria:** *TBD*

### 1.3.5.5 Calibration Model

**Definition:** The calibration model will be used for initial LSWT and TSWT checkout and acceptance, and for periodic diagnostics over the life of the tunnel. The model will be used to map tunnel performance and provide, over the life of the two tunnels, a record of tunnel flow quality and changes to the flow quality.

**Requirements:** The calibration model configuration shall be such that an established database exists for comparison, or there will be a requirement to test the calibration model in an existing facility to establish a database. The model shall incorporate a moderate level of pressure instrumentation (around 200 pressures), a standard health diagnostic package (including, but not limited to, accelerometers and on-board Angle of Attack transducers), an internal balance mount and on-board analog-to-digital processors for all output.

**Criteria:** The calibration model will be designed in accordance with the applicable Model Design Criteria. Configuration, instrumentation, surface finish are **TBD**

### **1.3.6 Auxiliary Electrical Distribution and Predictive Maintenance Systems**

**Definition:** The auxiliary electrical, control systems, and data acquisition consists of the electrical elements required for the proper performance of many of the auxiliary process components. Key elements included are: (1) the 480 volt AC Distribution System and (2) the Predictive Maintenance Data Acquisition System.

**Requirements:** The detailed requirements are contained in the subordinate sections.

#### **1.3.6.1 480 VAC Distribution System**

**Definition:** Provide the 480 volt auxiliary power distribution system.

**Requirement:** The 480 volt substation secondary switchgear and load centers; 480 volt motor control centers, power distribution panels; DC system equipment with batteries, chargers, distribution panels, and motor control; and the Uninterruptible Power System (UPS) with batteries, inverters, switching, and distribution panels; and wiring and cable tray/conduit systems shall be provided.

**Criteria:** **TBD**

#### **1.3.6.2 Predictive Maintenance Data Acquisition System**

**Definition:** Predictive maintenance data acquisition system includes all electrical/electronic components, cabling, and software required to monitor the health of the tunnel complex's auxiliary systems, provide indications for nonscheduled maintenance, and predict normal maintenance schedules for components/subsystems. This Section does not include sensors.

**Requirements:** The predictive maintenance system shall acquire data at a rate and accuracy to ensure readiness of complex to operate. The system will utilize redundant sensors where necessary to minimize nuisance trips due to errors in individual sensors and system noise. Advanced on line Artificial Intelligence techniques are needed to minimize maintenance requirements and rapidly identify and isolate problems in specific components when operational status is threatened. Communication is required between this system and control systems for tunnels and auxiliary systems.

**Table 1.3.6.2.a Predictive Maintenance Data Acquisition System Requirements**

<b>Parameter</b>	<b>Requirement</b>
System availability/reliability (%)	<i>TBD during Final Design</i>
Data sample rate	<i>TBD during Final Design</i>
Data accuracy	<i>TBD during Final Design</i>
Solution time for failure identification	<i>TBD during Final Design</i>
Communication rate to control systems	<i>TBD during Final Design</i>

**Criteria:** *TBD*

### **1.3.7 Auxiliary Process Systems Integrated Systems Testing**

**Definition:** The Auxiliary Process Systems sub-systems will be tested to demonstrate performance to specified levels. The work associated with shop tests is included with individual work packages. Once installed, subsystem checkouts and integrated system tests will be performed to verify performance parameters.

#### **1.3.7.1 Integrated System Checkout**

**Definition:** The Auxiliary Process System checkout is initiated when all of the system-level component checks have been completed and any significant deficiencies, identified in the process, have been corrected. An Integrated Systems Review (ISR) will be conducted to validate readiness prior to initiation of the integrated system testing of the Auxiliary Process Systems.

**Requirements:** The integrated system testing matrix shall include operation of all of the systems to the boundaries of the performance envelope to determine and document the safe limits of the facility operation. A tiered approach to integration of the system testing requirements shall be utilized to ensure equipment and personnel safety during checkout. A comprehensive checkout plan which describes the required elements of the Auxiliary Process System integrated system testing shall be prepared as part of this work element.

**Criteria:** *TBD*

#### **1.3.7.2 Auxiliary Process System Calibration**

**Definition:** Validation and calibration of the Auxiliary Process Systems includes the activities associated with the measurement of all system parameters over the range of facility test conditions to (1) validate compliance to requirements (flow rate, pressure, speed and accuracy of control, etc.) and (2) provide a basis for the development of the system calibration.

**Requirements:** This work element includes all labor, materials and utilities required to conduct the Auxiliary Process System validation/calibration from planning through calibration. An Operational Readiness Review (ORR) is conducted prior to the initiation of

validation/calibration testing in the facility. The ORR provides a comprehensive assessment of the facility, equipment, procedures, staffing and overall readiness for initiation of validation/calibration testing.

Criteria: *TBD*

#### 1.3.7.3 Provisioning

Definition: This work element provides all of the equipment required to maintain the productivity of the Auxiliary Process Systems during normal operations. The equipment will include all of the routinely replaced parts which can fail and must be available for rapid replacement.

Requirements: *TBD*

Criteria: *TBD*

## 1.4 LOW SPEED WIND TUNNEL (LSWT)

### Definition:

The Low Speed Wind Tunnel (LSWT) will have the following major features: a closed circuit, pressurized air, wind tunnel; a removable plenum and test section; a plenum and test section pressure/vacuum isolation system; high productivity; and superior flow and data quality.

**Requirements:** Specific LSWT requirements are given in Tables 1.4.a through j

**Table 1.4.a LSWT Performance Requirements**

Performance Requirements	See Figure 1.4.a
Mach Number Range	0.05 to 0.6
Total Pressure Range	0.07 to 5 atm
Test Section Shape	Rectangular, With Fillets
Test Section Size	20 x 24 ft Area <i>TBD</i>
Size of Fillets	<i>TBD</i>
Test Section Length	<i>TBD</i>
Maximum Temperature °F	Ambient + 30°
Test gas	air
Drive Power Design Point	M = 0.3, Pt = 5 atm, Tt = 100°F, Model Drag of 24,000 lbs

**Table 1.4.b LSWT Acoustics Requirements**

Acoustics Requirements	
In-Flow and Out-of-Flow Noise Specifications	See Figure 1.4.b
Anechoic Chamber	Yes, For Open Jet Test Capability
Acoustic Frequency Range	100-20,000 Hz
Open Jet Length	45 feet
Maximum Measurement Radius	40 feet
Directivity Angles	60° forward to 70° aft
Total Pressure During Acoustic Testing	One atmosphere
Test Section Type	Open Jet

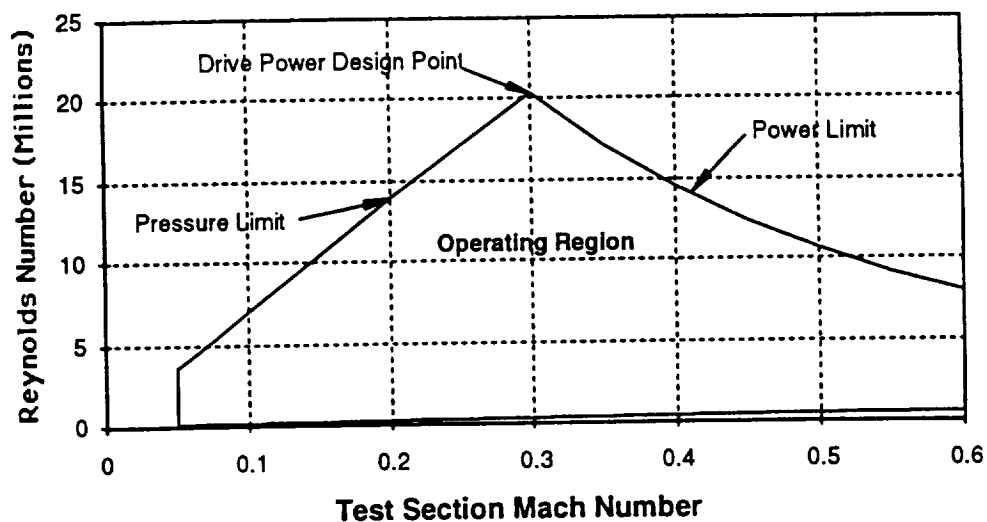


Figure 1.4.a LSWT Performance Envelope  
(Full Span Model, Reference Length -  $c_{bar} = 2.13$  feet)

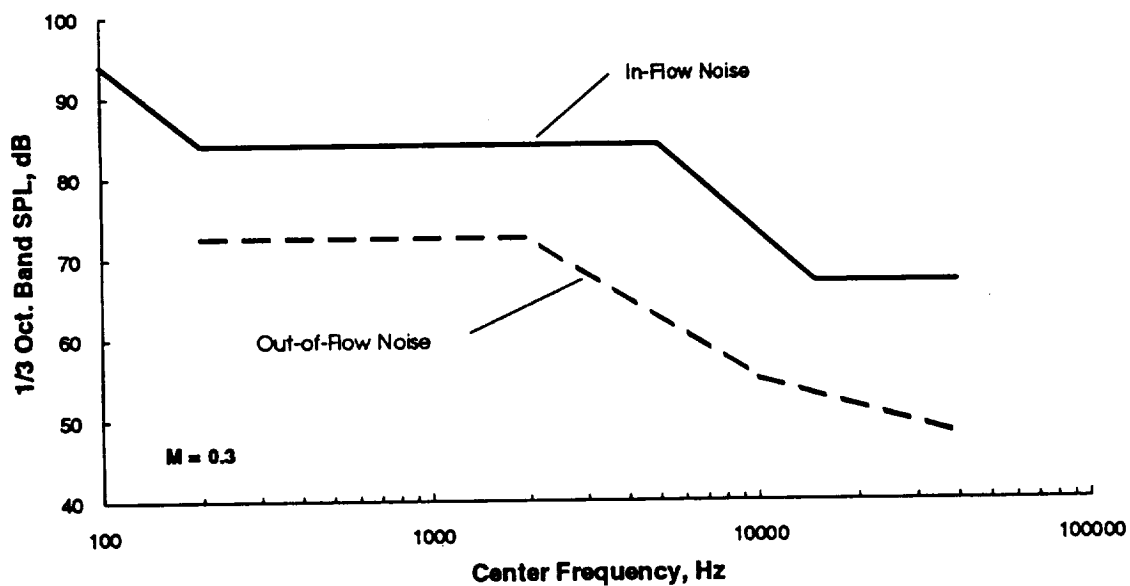


Figure 1.4.b LSWT Background Noise

Table 1.4.c LSWT Productivity Requirements

Productivity Requirements	
Average Productivity Rate Using Benchmark Test Program (See Appendix A.4)	5 Polars/Occupancy Hour
Removable Plenum and Test Section Carts	Yes
Cart Quantities and Types	4 (1 Slotted Rear Sting, 2 Slotted Floor Mount, 1 Open Jet Support)
Tunnel Pressure Isolation System	Yes

Table 1.4.d LSWT Data Quality Requirements

Data Quality Requirements		
Flow Quality	Closed Jet	Open Jet
Test Volume for Flow Quality Requirements	<i>TBD</i>	<i>TBD</i>
Total Temperature Distribution	$\pm 1.0^{\circ}\text{F}$ , Within Test Volume	$\pm 1.0^{\circ}\text{F}$ , Within Test Volume
Turbulence, %	0.04 Longitudinal, 0.08 Vertical, 0.08 Lateral, Within Test Volume	0.2 Longitudinal, 0.12 Vertical, 0.12 Lateral, Within Test Volume
Noise, RMS	59.4 dB, Within Test Volume	59.4 dB, Within Test Volume
Stream Angle Deviation	$< \pm 0.1^{\circ}$ , Within Test Volume	<i>TBD</i> , Within Test Volume
Stream Angle Gradient	0.01°/ft, Along Any Line Within Test Volume	<i>TBD</i> /ft, Along Any Line Within Test Volume
Mach Number Distribution	$\pm 0.001$ Along Tunnel Centerline $\pm 0.001$ In a Cross Section At Center Of Model Rotation $\pm 0.0005/\text{ft}$ Along Centerline Over Length Of Test Volume	$\pm \textit{TBD}$ Along Tunnel Centerline $\pm \textit{TBD}$ In a Cross Section At Center Of Model Rotation $\pm \textit{TBD}/\text{ft}$ Along Centerline Over Length Of Test Volume
Tunnel Stability: Total Pressure Total Temperature Mach Number	$\pm 1$ psf Over a 10 sec Period $\pm 0.5^{\circ}\text{F}$ Over a 10 sec Period $\pm 0.0005$ Over a 10 sec Period	$\pm 1$ psf Over a 10 sec Period $\pm 0.5^{\circ}\text{F}$ Over a 10 sec Period $\pm 0.0005$ Over a 10 sec Period

Table 1.4.e LSWT Data Acquisition System Requirements

Data Acquisition System Requirements	
Overall System Accuracy (for any signal)	<i>TBD</i>
Overall System Response or Settling Time (for any parameter)	<i>TBD</i>

Table 1.4.f LSWT Model Propulsion Requirements

Model Propulsion Requirements	Turbine Power Simulator	High Bypass Simulator	HSCT (Simultaneous) Outer/Inner	Fighter
Mass Flow Rate, lbs/sec	35	30	40/40	100
Temperature At Model, °F	400	200	500/1500	200
Pressure At Model, psia	3000	300	150/150	2500
Run Distribution	Continuous	Continuous	Continuous	15 Minutes Out Of Every 30 Minutes

Table 1.4.g LSWT Closed Jet Model Loads

Closed Jet Model Loads			
	Rear Strut Mount Full Span No Roll	Rear Strut Mount Full Span With Roll	Floor Mount Semispan
Lift Force, lbs	±81,000	±56,000	±112,000
Drag Force, lbs	±18,000	±12,000	±24,000
Side Force, lbs	±7,000	±5,000	±18,000
Pitching Moment, ft-lbs	±41,000	±24,000	±94,000
Rolling Moment, ft-lbs	±37,000	±21,000	±840,000
Yawing Moment, ft-lbs	±19,000	±11,000	±118,000
Note: Loads are for unpowered models referenced to 1/4 mean aerodynamic cord at the plane of symmetry (5 atmospheres)			

Table 1.4.h LSWT Closed Jet Model Positioning Requirements

Closed Jet Model Positioning Requirements		
	Rear Strut Mount	Floor Mount
Pitch Angle Range, degrees	<i>TBD</i>	<i>TBD</i>
Pitch Speed Range, degrees/sec	<i>TBD</i>	<i>TBD</i>
Pitch Positioning Accuracy, degrees	<i>TBD</i>	<i>TBD</i>
Yaw Angle Range, degrees	None	<i>TBD</i>
Yaw Speed Range, degrees/sec	None	<i>TBD</i>
Yaw Positioning Accuracy, degrees	None	<i>TBD</i>
Roll Angle Range, degrees	<i>TBD</i>	None
Roll Speed Range, degrees/sec	<i>TBD</i>	None
Roll Positioning Accuracy, degrees	<i>TBD</i>	None

Table 1.4.i LSWT Open Jet Model Loads

Open Jet Model Loads			
	Rear Strut Mount Full Span No Roll	Rear Strut Mount Full Span With Roll	Floor Mount Semispan
Lift Force, lbs	±16,200	±11,200	±22,400
Drag Force, lbs	±3,600	±2,400	±4,800
Side Force, lbs	±1,400	±1,000	±3,600
Pitching Moment, ft-lbs	±8,200	±4,800	±18,800
Rolling Moment, ft-lbs	±7,400	±4,200	±168,000
Yawing Moment, ft-lbs	±3,800	±2,200	±23,600

Note: Loads are for unpowered models referenced to 1/4 mean aerodynamic cord at the plane of symmetry (1 atmosphere)

Table 1.4.j LSWT Open Jet Model Positioning Requirements

Open Jet Model Positioning Requirements		
	Rear Strut Mount	Floor Mount
Pitch Angle Range, degrees	<i>TBD</i>	<i>TBD</i>
Pitch Speed Range, degrees/sec	<i>TBD</i>	<i>TBD</i>
Pitch Positioning Accuracy, degrees	<i>TBD</i>	<i>TBD</i>
Yaw Angle Range, degrees	<i>TBD</i>	<i>TBD</i>
Yaw Speed Range, degrees/sec	<i>TBD</i>	<i>TBD</i>
Yaw Positioning Accuracy, degrees	<i>TBD</i>	<i>TBD</i>
Roll Angle Range, degrees	<i>TBD</i>	None
Roll Speed Range, degrees/sec	<i>TBD</i>	None
Roll Positioning Accuracy, degrees	<i>TBD</i>	None

### 1.4.1 Pressure Vessel System

**Definition:** The pressure vessel system includes all components of the outer pressure containing shell of the LSWT, with the exception of the following:

- The LSWT Rolling Plenum Shell- included in Section 1.4.2.
- The LSWT Compressor Section Shell - included in Section 1.4.4.

The pressure vessel system also includes the following: foundation, structural supports, pressure shell with shell penetrations to the first flange, external stiffening rings, and tunnel isolation valves.

#### 1.4.1.1 Foundation

**Definition:** The foundation for the tunnel pressure vessel system is site dependent. It is a reinforced concrete structure, supporting the weight of the pressure shell (including the weight of water during hydrostatic testing), the tunnel internal structures, and the tunnel enclosure. The foundation consists of a reinforced concrete basemat with embedded plates and bolts to facilitate the attachment of tunnel enclosure steel and pressure shell supports and anchors. It is a stepped design, varying from grade level in the building and model preparation areas to well below grade underneath the tunnel.

**Requirements:** The LSWT pressure shell shall be supported on a common foundation. The intent is to keep a constant elevation for the cart rails from the preparation hall into the tunnel. The tunnel shell anchor point and anchor/foundation stiffness requirements are *TBD*.

#### Criteria:

**Table 1.4.1.1.a LSWT Foundation Criteria**

Parameter	Requirement
Design Standards	<i>TBD</i> , Site Dependent
Allowable Soil/Pile Capacity	
Seismic/Earthquake Requirements	
Foundation Loads	<i>TBD</i> , Design Process
Empty Pressure Shell Weight	
Weight of Test Section Internals	
Weight of Water During Hydro Test	
Dynamic Loads	
Tunnel Operational Loads	<i>TBD</i> , Ref.: Aerolines Study

### 1.4.1.2 Structural Supports

**Definition:** The structural supports are vertical columns and cross braces which support and stabilize the tunnel shell and internals. Connections are provided to permit longitudinal and lateral movement of the tunnel with respect to the single fixed anchor point.

**Requirements:** The structural supports shall anchor the tunnel shell to the foundation, provide vertical support for the tunnel, and allow longitudinal and lateral movement of the shell relative to the tunnel anchor point.

**Criteria:**

**Table 1.4.1.2.a LSWT Structural Support Criteria**

Parameter	Requirement
Design Standards	AISC Steel Construction Code
Allowable Tunnel Deflections	<i>TBD</i> , Ref. Aerolines and Plenum/Cart Study
Spacing and Centerline Height of Tunnel	<i>TBD</i> , Design Process
Design Loads	<i>TBD</i> , Design Process
Empty Pressure Shell Weight	
Weight of Test Sect. Internals	
Weight of Water, Hydro Test	
Dynamic Loads	
Anchor Point Location and Stiffness	<i>TBD</i> , Ref. Aerolines Study

### 1.4.1.3 Pressure Shell

**Definition:** The pressure shell is the outer structure in the wind tunnel, which contains the pressure. It is also the flow boundary around the tunnel circuit, except through the settling chamber and high speed diffuser regions. The pressure shell has the following sub-elements: Test Section/Plenum Outer Shell, Downstream Isolation Shell, Test Section Diffuser Shell, Corner #1, Cross Leg #1, Corner #2, Tail Section, Compressor Diffuser Shell, Corner #3, Crossleg #2, Corner #4, Upstream Transition/Wide Angle Diffuser, Settling Chamber Shell, Upstream Isolation Shell, Fixed Plenum Shell.

The following tunnel sections are also pressure vessels, but have been included in other work packages for convenience:

- The Rolling Plenum - included in WBS 1.4.2.
- The Compressor Section Shell - included in WBS 1.4.4.

This work package also includes external stiffening rings, shell penetrations and internal supports for components located in the shell, and all activities related to obtaining an ASME Code stamp.

**Requirements:** The pressure shell shall be constructed of curved plates, ring girders, stringers, flanges, bulkheads, gussets, and stiffeners. The pressure shell shall interface with the test section plenum and compressor sections. Penetrations shall be required for instrumentation, tunnel access, pressurization/evacuation, drive shaft, manways, cooling water, and lubrication. The tunnel cross section shall be circular with square corner and conical sections.

**Criteria:**

**Table 1.4.1.3.a LSWT Pressure Shell Criteria**

Parameter	Requirement
Standards	The pressure shell is designed, constructed, inspected, tested, and U stamped in accordance with the ASME Code Sect. VIII.
Operating Pressure Range:	14 psig external to 66 psig internal pressure
Design Pressure Range	15psig external to 70 psig internal pressure
Design Temperature	0 to 140 ° F
Design Life	Definition and operational cycles <i>TBD</i>
Overall Dimensions	<i>TBD</i> , Ref.: Aeroline Study
Material	ASME Code Approved
Location, Size and Loads of Penetrations	<i>TBD</i> , Design Process
Coatings	Interior and exterior surfaces shall be painted

**1.4.1.4 Isolation Valves**

**Definition:** The upstream and downstream isolation valves are two large gate valves, one upstream and one downstream of the test section, which can be rapidly actuated to isolate the high pressure air from the test section area. The test section area can then be rapidly vented, so models can be quickly modified in place or changed using the movable plenum/test section cart concept. The isolation valves include the following sub-elements: Housing/Flange, Gate Structure, Gate Guide Mechanism, Gate Actuation System, Sealing System, Power System, Controls System.

**Requirements:** Two sliding gate valves are required, one upstream and one downstream of the test section, each consisting of flat or semi-elliptical heads with full edge flanges. The valves may be designed horizontally or vertically. Each valve shall be powered by a quick acting drive system. The gate of the valve slides in a guided rail system. The valves shall be stored in a well beneath or to the side of the tunnel flow stream completely enclosed in the pressure plenum. Seals shall be required to prevent leakage past the gates in the open and closed positions under a wide range of operating conditions.

**Criteria:**

Table 1.4.1.4.a LSWT Isolation Valve Criteria

Parameter	Requirement
Standards	The isolation valves are designed, constructed, inspected, tested, and U-stamped in accordance with the ASME Code Section VIII.
Operating Pressure Range	14 psig external to 66 psig internal pressure
Design Pressure Range	15 psig external to 70 psig internal pressure
Design Temperature	0 to 140 ° F
Overall Dimensions	<i>TBD</i> , Ref.: Aeroline Study
Size	<i>TBD</i> ,
Material	ASME Code Approved
Seals	Active trapped continuous pressure seals on mating surfaces of pressure shell bulkhead in open and closed positions. Leakage Rate (open/closed): <i>TBD</i>
Opening/Closing Speeds	<i>TBD</i> , Ref.: Productivity Study
Allowable Steps/Gaps In Flow Surface	<i>TBD</i> , Ref.: Aeroline Study
Automated Controls	<i>TBD</i>

## 1.4.2 Plenum / Test Section System

### 1.4.2.1 Rolling Plenum

**Definition:** The rolling plenum is a removable section of the tunnel circuit, which houses the test section. It can be disconnected from the stationary pressure shell and rolled out of the circuit for the purpose of making rapid model changes. The rolling plenum pressure shell includes penetrations for personnel access and data/instrumentation connections. The rolling plenum includes the following sub-elements: Rolling Plenum Shell, Plenum Internal Structure, Plenum External Structure, Plenum Drive System, Plenum Alignment and Latching System, ... Plenum Sealing System, Plenum Control System.

**Requirements:** Achievement of the high productivity requirements for the facility is partially dependent on the successful and reliable performance of the tunnel carting system. The rolling plenum is a critical component in the tunnel carting system. The rolling plenum can either be positioned in front of one of various cart bays for loading and unloading of the test section / model support system assembly or be moved into the tunnel circuit for operational testing. Optimization of the process for making in-place model changes and of process for interchanging models in the tunnel circuit is a significant factor in being able to meet the stringent productivity requirements. The system productivity requirements are presented in Section 1.4.0 for the selected Benchmark Test Program outlined in Appendix B.

Special, quick exchange type penetrations ports shall be used to pass electrical, data acquisition, and instrumentation leads through the pressure shell. Very precise alignment of the flow surfaces is required in order to maintain the flow quality requirements. An automatic latching

and alignment mechanism shall be used to quickly and positively align and lock the rolling plenum in place. A sealing system shall be used to minimize leakage through the pressure vessel.

#### Criteria:

**Table 1.4.2.1.a LSWT Rolling Plenum Criteria**

Parameter	Requirement
Standards	The rolling plenum is designed, constructed, inspected, tested, and U-stamped in accordance with the ASME Code Section VIII.
Operating Pressure Range	14 psig external to 66 psig internal pressure
Design Pressure Range	15 psig external to 70 psig internal pressure
Design Temperature	0 to 140 ° F
Design Life	<i>TBD</i> , Ref.: Aeroline Study
Internal Loads	<i>TBD</i> , Ref.: Aeroline Study
Shell Materials	ASME Code Approved
Installation/Removal Speed	<i>TBD</i> , Ref.: Productivity Study
Alignment Requirements During Installation	<i>TBD</i> , Ref.: Aeroline Study
Allowable Steps/Gaps At Mating Flanges	<i>TBD</i> , Ref.: Aeroline Study
Overall Stiffness Requirements For External Balance	<i>TBD</i> , Ref.: Plenum/Cart Study
Reliability	<i>TBD</i> , Ref.: Productivity Study

#### **1.4.2.2 Sting Mount Test Section**

**Definition:** The sting mount test section is a four sided welded and machined steel structure with adjustable sidewalls, which houses the Rear Sting Model Support System, Section 1.4.2.4. All walls of the test section have slots. The sting mount test section includes the following sub-elements: Outer Structural Frame, Walls/Actuators, Drive System, Alignment & Latching System, Sealing System, Controls System.

**Requirements:** The sting mount test section is one of three interchangeable test section types. The sting mount test section and the sting mount model support system shall be installed in the rolling plenum as an integral unit. Optimization of the process for interchanging test sections and models in the tunnel circuit is a significant factor in being able to meet the stringent productivity requirements. The system productivity requirements are presented in Section 1.4.0 for the selected Benchmark Test Program outlined in Appendix B.

Very accurate fabrication and machining tolerances and very precise alignment of the flow surfaces shall be required in order to maintain the flow quality requirements in the test section. An automatic latching and alignment mechanism shall be used to quickly and positively align and lock the sting mount test section in place. A sealing system shall be used to minimize

leakage into the test section from the plenum area. Observation windows shall be provided in the test section, as specified below. Model access for efficiently making minor model changes in the tunnel is a critical productivity item.

**Criteria:**

**Table 1.4.2.2.a LSWT Sting Mount Test Section Criteria**

Parameter	Requirement
Standards	<i>TBD</i>
Inside Dimensions	See Table 1.4.a
Test Section Fillets	See Table 1.4.a
Test Section Area	See Table 1.4.a
Flow Quality In Test Section	See Table 1.4.d
Installation/Removal Speed	<i>TBD</i> , Ref.: Productivity Study
Design Loads	<i>TBD</i> , Ref.: Aeroline Study
Alignment Requirements During Installation	<i>TBD</i> , Ref.: Aeroline Study
Overall Stiffness Requirements	<i>TBD</i> , Ref.: Plenum/Cart Study
Observation Windows Size, Number, & Spacing	<i>TBD</i>

**1.4.2.3 Floor Mount Test Sections**

**Definition:** The floor mount cart is a four sided, welded and machined steel structure with adjustable sidewalls which houses the external balance and floor mount model support assembly, Section 1.4.2.5. All walls of the test section have slots. The floor mount test sections include the following sub-elements: Outer Structural Frame, Walls/Actuators, Drive System, Alignment & Latching System, Sealing System, Control System.

**Requirements:** Two identical floor mount test sections are required. The floor mount test sections are critical components in the tunnel carting system. The floor mount test sections include three interchangeable test sections. The floor mount test sections and the floor mount model support system/ external balance are installed in the rolling plenum as an integral unit. Optimization of the process for interchanging test sections and models in the tunnel circuit is a significant factor in being able to meet the stringent productivity requirements. The system productivity requirements are presented in Section 1.4.0 for the selected Benchmark Test Program outlined in Appendix B.

Very accurate fabrication and machining tolerances and very precise alignment of the flow surfaces is required in order to maintain the flow quality requirements in the test section. An automatic latching and alignment mechanism shall be used to quickly and positively align and lock the sting mount test section in place. A sealing system shall be used to minimize leakage into the test section from the plenum area. Observation windows shall be provided in the test section, as specified below.

**Criteria:****Table 1.4.2.3.a LSWT Floor Mount Test Section Criteria**

Parameter	Requirement
Standards	<i>TBD</i>
Inside Dimensions	See Table 1.4.a
Test Section Fillets	See Table 1.4.a
Test Section Area	See Table 1.4.a
Flow Quality In Test Section	See Table 1.4.d
Installation/Removal Speed	<i>TBD</i> , Ref.: Productivity Study
Design Loads	<i>TBD</i> , Ref.: Aeroline Study
Alignment Requirements During Installation	<i>TBD</i> , Ref.: Aeroline Study
Overall Stiffness Requirements	<i>TBD</i> , Ref.: Plenum/Cart Study
Observation Windows Size, Number, & Spacing	<i>TBD</i>

**1.4.2.4 Rear Sting Model Support System**

**Definition:** The rear sting model support system is the mechanical structural system that accurately positions sting mounted models in the test section under high aerodynamic loading conditions. The rear sting model support system includes a pitch assembly and a roll coupling, which attaches to the strut by a mechanical interface. The rear sting model support system includes the following sub-elements: Vertical Strut, Pitch Mechanism, Vertical Translation Mechanism, Roll Mechanism, Walls/Actuators, Drive System, Alignment & Latching Mechanism, Sealing System, Auxiliary Systems, Control & Data Acquisition System.

**Requirements:** Sting supported models using internal balances shall be supported from a pitch strut located in the downstream portion of the test section. The rear sting model support system shall be moved from the tunnel, when not in use. The pitch mechanism must be capable of maintaining a constant model height throughout the pitch range with various sting lengths (i.e. variable pitch point), and be capable of vertical traverse motion at any constant angle of pitch within the capable range. It must be designed for specified model loads with a cross section designed for minimal blockage effects.

Provisions for simultaneous pitch and roll shall be required. The strut cross section shall be contoured to minimize aerodynamic losses and interference with test section flow qualities. Provisions must be made for instrumentation, air and power ducting in the vertical strut and model support sting.

**Criteria:**

- Standards: Models Design Criteria
- Model Loads See Table 1.4.g

- Positioning Requirements: See Table 1.4.h
- Deflection or Stiffness Criteria: *TBD*
- Blockage Criteria: *TBD*, Ref.: Aeroline Study

#### 1.4.2.5 Floor Mount Model Support Systems

**Definition:** The floor mount model support system is a second mechanical structural system that accurately positions floor mounted models in the test section under high aerodynamic loading conditions. The floor mount model support system includes a pitch mechanism and a yaw turntable. An external balance is used to obtain force measurements in conjunction with the floor mount model support systems. This work package includes both single strut and three strut supports with pitch linkages or actuators to provide pitch angle positioning and a turntable to provide yaw angle positioning. This work package includes the interface support structure, lift mechanism, and any latching mechanisms required between the external balance and rolling plenum and external balance and floor mount test section. The external balance is a highly accurate advanced technology balance, mounted in the plenum area, under the test section floor. A lifting mechanism is provided for balance removal. Calibration of the external balance is covered in Section 1.3.7.6. The floor mount model support systems include the following sub-elements: Pitch Mechanism, Yaw/Turntable Mechanism, Walls/Actuation System, Drive System, Alignment & Latching Mechanism, Sealing System, Auxiliary Systems, Controls & Data Acquisition System, External Balance.

#### Requirements:

##### Floor Mount Model Support System:

Two identical floor mount model support systems and two identical external balances are required. The floor mount model support systems and external balances shall be transportable as an integral units between the build-up area and test section. The external balance is raised when the floor mount test section is moved and lowered when the external balance is in the installed position. It interfaces with a steel foundation permanently mounted in the movable plenum. Pitch motion and yaw positioning is required. Roll positioning is not required. Efforts must be made during the design process to insure adequate stiffness in the balance support structure.

##### External Balance:

The external balance shall fit into the LSWT plenum area. The external balance shall have the following characteristics: Automatic component decoupling by computer, real time acquisition of measured values, frame ground support which is 100 times the flexural stiffness, and no wear. The external balance shall have design loads, accuracy, repeatability, and resolution requirements as shown in the design criteria, with the interchangeable cart concept.

#### Criteria:

Table 1.4.2.5.a LSWT External Balance Criteria

Parameter	Requirement	
Standards	Model Design Criteria	
Model Loads	See Table 1.4.g	
Positioning Requirements	See Table 1.4.h	
External Balance Accuracy Requirements	Accuracy, %	Repeatability, %
Lift	0.02	0.007
Drag	0.01	0.002
Side Force	0.05	0.017
Pitching Moment	0.02	0.007
Rolling Moment	0.05	0.017
Yawing Moment	0.05	0.017
Deflection/Stiffness Criteria	<i>TBD</i> , Ref.: Aeroline Study	
Blockage Criteria	<i>TBD</i> , Ref.: Aeroline Study	
Space Requirements	<i>TBD</i> , Ref.: Aeroline Study	
Installation/Removal Time	<i>TBD</i> , Ref.: Productivity Study	

## 1.4.2.6 Test Support and Calibration Hardware

**Definition:** The test support and calibration hardware includes the following sub-elements:

- 1.4.2.6.1 Calibration Hardware
- 1.4.2.6.2 Model Handling Equipment
- 1.4.2.6.3 Stings and Struts
- 1.4.2.6.4 Internal Balances
- 1.4.2.6.5 Ground Planes

## 1.4.2.6.1 Calibration Hardware

**Definition:** Calibration hardware is the instrumentation and test hardware required to measure flow quality in the LSWT.

**Requirements:** A means of measuring flow quality shall be provided. The following types of flow quality measurements will be made over the entire test section area to within one foot of all walls, floors, ceilings and fillets:

- Mach Number
- Turbulence Levels
- Flow Angularity
- Total Pressure
- Total Temperature
- Acoustic Data
- Boundary Layer Profiles

The measurement devices shall provide the means for supplying time averaged data values, as well as instantaneous data values. All measurement devices shall be designed for use over the entire range of tunnel operation. No model or sting will be in the tunnel during calibration measurements. The calibration measurements shall be integrated into the tunnel data acquisition system.

In addition to measuring the flow data, a means of surveying the test section shall be provided. This system shall be capable of positioning the measuring devices very accurately and shall be fully automated such that the time to complete a survey is optimized. The specific requirements for the calibration devices are **TBD**.

**Criteria:** This hardware will be designed in accordance with the Model Design Criteria. Specific instrumentation, materials, etc., are **TBD**.

#### 1.4.2.6.2 Model and Sting Handling Equipment

**Definition:** Model and sting handling equipment is needed in the various build-up bays to support and transport the model components until they are mounted to the sting, strut, etc. The cart will be used to place models into the individual test sections, and to remove the models from the test section after completion of the test(s).

**Requirements:** The handling equipment shall consist of a cart type device with a lifting capability. A cart shall be provided for each build-up area. Each cart shall have the capability of supporting sting mounted models up to a 20 foot span and a weight of 2000 lb, and stings up to 20 foot overall length and a weight of 25,000 lb.

**Criteria:** **TBD**

#### 1.4.2.6.3 Stings and Struts

**Definition:** The LSWT will accommodate a variety of models and mounting options, including stings, struts, rod supports, and floor or wall semi-span model mounts. An assortment of stings, struts, and other mounting hardware items adequate for activation will be provided.

**Requirements:**

For model loads see section 1.4

- **Stings:** Two sting configurations shall be provided. The stings shall mount either to the pitch strut or to the pitch strut roll mechanism through a common joint. The distance from the model pitch point to the pitch strut is **TBD**. Two stings of each size shall be provided to allow for model build-up activities while testing is underway for a total of four stings. Multiple adapters shall be provided to accommodate known user furnished balances and to provide for model positioning in the test section. The number of adapters required is **TBD**.

One adapter specially designed to handle large mass flow rates of propulsion simulation air (See Table 1.4.f).

- **Struts:** Two floor mounted strut systems are required for external balance testing. The single strut design shall incorporate air lines for propulsion simulation testing with Turbine Powered Simulators (TPS) or ejectors, and balance and/or sting mounting provisions. The air lines shall be sized for the specified propulsion simulation air requirements (See Table 1.4.f), and shall have passages for multiplexed data cables, balance cables, model utilities, etc. The triple strut support system shall have similar capability to the single strut, with activation of the aft strut to provide angle of attack capability, and will mount either to a solid floor insert or to a turntable. Both struts shall be rated to full model loads (See Table 1.4.g) with "infinite" fatigue life.
- **Semi-Span Model Mount:** The removable floor mount hardware shall include the turntable plate, blanking plates, and the balance adapter assembly. Any other components required to provide a common mounting interface between the external balance and semi-span models shall be included in this item.

**Criteria:** Each system will be designed in accordance with the Model Design Criteria. Other criteria is **TBD**.

#### 1.4.2.6.4 Internal Balances

**Definitions:** Internal balances are load measuring devices mounted inside of models to accurately determine aerodynamics forces on the model.

**Requirements:** For the LSWT, two high-range balances and two low-range balances shall be provided. Dummy balances of each balance type and size shall also be provided, with the same load range rating. The dummy balances shall have the same physical outline as the active balances. All taper gages, ring gages, etc. required to assure balance fit shall be supplied.

The high range LSWT balance shall have the load range specified in Section 1.4.g for the closed jet test section. The load range for the low-range balances is **TBD**. The balance accuracy requirements for the two load ranges are **TBD**.

**Criteria:** The internal balances and any dummy balances intended as test articles will be designed and built in accordance with the Model Design Criteria.

#### 1.4.2.6.5 Ground Planes

**Definition:** Ground planes are flat plates, which can be installed into the test section for certain tests, to simulate the effects of the ground on model data. Ground planes include the flat plate structure itself, and all auxiliary systems needed to operate and support the ground plane in the tunnel.

**Requirements:** Two types of ground planes are required: (1) Floor Mounted Ground Plane and (2) Ceiling Mounted Ground Plane

The floor mounted ground plane is mounted from the floor of the test section. Provisions for the floor mounted ground plane shall be provided in both sting mounted and floor mounted test sections. The requirements for the floor mounted test sections are *TBD*.

The ceiling mounted ground plane is similar to the floor mounted ground plane, except it is attached to the test section ceiling rather than the floor. The ceiling mounted ground plane shall also be compatible with both rear sting and floor mounted test section and model support types. The requirements for the ceiling mounted test sections are *TBD*.

**Criteria:** *TBD*

#### 1.4.2.7 Shuttle Cart

**Definition:** The shuttle cart is a general purpose lifting and handling device. It is used to move various test sections and model support systems from bay to bay in the Model Preparation Building. The shuttle cart includes the following sub-elements: Structural Frame, Drive Mechanism, Lift System, Auxiliary Systems, Controls System.

**Requirements:** The shuttle cart shall have the capacity to lift any of the test sections or model support systems and have the capability of accurately translating and positioning a load vertically up to 10 ft. The preparation hall shuttle cart is self powered and has the capability to operate independently of the rail system. One shuttle cart

**Criteria:**

- Standards: *TBD*
- Rate of Travel *TBD*
- Lift Capacity *TBD*, Design Process
- Payload Positioning Accuracy: *TBD*

#### 1.4.2.8 Open Jet Collector

**Definition:** The open jet collector extends into the flow in the rear of the open jet test section and collects the flow for entry into the high speed diffuser.

**Requirement:** The open jet collector and open jet nozzle extension will form an open jet test section geometry capable of steady flow operation up to Mach = 0.6. The collector shall be treated with acoustically absorbent material to prevent acoustic reflections back into the direction of the model or sensors.

**Criteria:**

- Standards: *TBD*
- Open Jet Flow Quality Requirements: See Table 1.4.d
- Collector Geometry: *TBD*, Ref.: Open Jet Test Section Studies
- Acoustic Material: *TBD*

**1.4.2.9 Open Jet Nozzle Extension**

**Definition:** The open jet nozzle extension connects to the contraction nozzle at station XXX and provides a flow surface that imparts low turbulence, highly steady flow to the open jet test section.

**Requirement:** The open jet test section shall provide acoustic testing for speeds up to  $M=0.6$ .

**Criteria:**

- Standards: *TBD*
- Open Jet Flow Quality Requirements: See Table 1.4.d
- Nozzle Extension Geometry: *TBD*, Ref.: Open Jet Test Section Studies

**1.4.2.10 Open Jet Rear Sting Model Support System**

**Definition:** The open jet rear sting model support system will mount to the open jet test section cart (1.4.2.14) and support a model in the flow stream up to the specified load limits throughout the model inclination envelope. The open jet rear sting model support system includes the following sub-elements: Vertical Strut, Pitch Mechanism, Yaw Mechanism, Vertical Translation Mechanism, Alignment & Latching Mechanism, Auxiliary Systems, Controls & Data Acquisition System.

**Requirement:** The open jet rear sting model support system shall hold the model for open jet testing in the air stream with the required position accuracy. All model support system wetted surface area shall be treated with acoustically absorbent material.

**Criteria:**

- Standards: Models Design Criteria
- Model Loads: See Table 1.4.i
- Positioning Requirements: See Table 1.4.j

#### 1.4.2.11 Open Jet Floor Mount Model Support System

**Definition:** The open jet floor mount model support system will mount to the open jet test section cart (1.4.2.14) and support a model in the flow stream up to the specified load limits throughout the model inclination envelope. Alternatively, the floor mount model support system can be mounted to the floor mount traversing system, which will allow variable model positioning in the test section to satisfy directivity requirements. The open jet floor mount model support system includes the following sub-elements: Model Mounting Interface, Pitch Mechanism, Yaw/Turntable Mechanism, Vertical Translation Mechanism, Alignment & Latching Mechanism, Auxiliary Systems, Controls & Data Acquisition System

**Requirement:** The open jet floor mount model support system shall hold the model for open jet testing in the air stream with the required position accuracy. All model support system wetted surface area shall be treatable with acoustically absorbent material.

**Criteria:**

- |                             |                        |
|-----------------------------|------------------------|
| • Standards:                | Models Design Criteria |
| • Model Loads:              | See Table 1.4.i        |
| • Positioning Requirements: | See Table 1.4.j        |
| • Deflection Requirements:  | <b>TBD</b>             |
| • Blockage Criteria:        | <b>TBD</b>             |

#### 1.4.2.12 Open Jet Floor Mount Traversing System

**Definition:** The open jet floor mount traversing system provides a means to position the model at various streamwise positions in the open jet test section to satisfy directivity requirements. The open jet floor mount traversing system includes the following sub-elements: Mounting Frame, Carriage, Drive Mechanism, Auxiliary Sys., Controls & Data Acquisition Sys.

**Requirement:** The traverse system shall be sized to move, support and maintain a model in the flow, while subject to the combined model and floor mount support system loads. The traverse range shall be sufficient to provide measurement radius at specified directivity angles not met by design of the anechoic chamber (1.4.2.15).

**Criteria:**

- |                       |  |
|-----------------------|--|
| • Standards:          | Models Design Criteria                                     |
| • Measurement Radius: | 40 ft  |
| • Directivity Angles: | 60° Forward From Model Center<br>70° Aft From Model Center |

- Traverse Positioning Range: *TBD*
- Traverse Positioning Accuracy: *TBD*
- Traverse Speed Range: *TBD*
- Stiffness Requirements: *TBD*

#### 1.4.2.13 Open Jet Microphone Traversing System

**Definition:** The open jet microphone traversing system provides a means to measure sound levels at various points or volumes in the open jet test section. This system is a computer controlled bi-directional traversing system that moves a series of microphones through a linear traverse to map the acoustic field. The open jet microphone traversing system includes the following sub-elements: Microphone Mounting Rake, Support Structure, Drive Mechanism, Rails/Mounting Attachments, Controls & Data Acquisition System.

**Requirement:** The open jet microphone traverse system shall be made sufficiently adaptable to provide a means of measuring sound levels at different locations in the anechoic chamber, depending upon the particular test. The rake shall be capable of in-flow or out-of-flow operation. For in-flow operation, the rake shall have streamlined acoustic treatment to minimize flow disturbances. For out-of-flow tests, the rake shall have some form of acoustic treatment, but streamlining will not be as important. The rake shall hold up to 12 microphones in a variable mounting scheme that allows the number and placement of the microphones to vary according to test specifications. Further, the rake traversing system shall mount onto the open jet test cart. Finally, the movement of the traverse shall be computer controlled from a master computer that will coordinate traverse movement with data acquisition to produce a highly productive data system.

#### Criteria:

- |                                       |                        |
|---------------------------------------|------------------------|
| • Standards:                          | Models Design Criteria |
| • Traversing Range:<br>-X and Y       | <i>TBD</i>             |
| • Traversing Speed Range:<br>-X and Y | <i>TBD</i>             |
| • Positioning Accuracy:<br>-X and Y   | <i>TBD</i>             |
| • Stiffness Requirements:<br>-X and Y | <i>TBD</i>             |

#### 1.4.2.14 Open Jet Test Section Cart

**Definition:** The open jet test section cart incorporates the elements of the open jet test section on a self-propelled cart assembly. The cart contains provision for installing the model mounting systems included in 1.4.2.10 and 1.4.2.11, the open jet microphone traversing system included in 1.4.2.13 and the hot jet propulsion system included in 1.3.3. The open jet test section cart includes the following sub-elements: Structure, Drive Mechanism, Auxiliary Systems, and Control System.

**Requirement:** The open jet test section cart shall have sufficient load carrying capability to support and transport the nozzle lip extension, flow collector, model and model support system, an acoustic traverse system, and associated systems between and into the test cell and model preparation bays at a speed consistent with the productivity requirements for the facility. The open jet test section provides acoustic testing capability for speeds up to  $M=0.6$ . The open jet test section cart shall accommodate the hot jet propulsion system. All acoustically absorbent treatment in the open jet test section shall be heat and flame resistant, consistent with hot jet propulsion system heat loads (See Section 1.3.3).

**Criteria:**

- |  |  |
|--|--|
| • Standards:   | <i>TBD</i>                                       |
| • Open Jet Length:<br>(Between Nozzle Exit And Collector Entrance) | At Least 45 ft.                                  |
| • Load Carrying Capability   | <i>TBD</i> , Design Process                      |
| • Design Loads   | <i>TBD</i> , Ref.: Aeroline Study & Design       |
| • Alignment Requirements:<br>During Installation                   | <i>TBD</i> , Ref.: Aeroline Study &              |
| • Overall Stiffness:   | <i>TBD</i> , Ref.: Open Jet Test Section Studies |
| • Background Noise Level:  | See Table 1.4.b                                  |
| • Open Jet Flow Quality Requirements:                              | See Table 1.4.d                                  |

#### 1.4.2.15 Anechoic Chamber

**Definition:** The anechoic chamber is an acoustically treated test cell. The Anechoic Chamber includes the following sub-elements: Anechoic Chamber Door, Anechoic Chamber Wall Treatment, Wall Acoustic Treatment Support System, Anechoic Chamber Floor Acoustic Treatment.

**Requirement:** The anechoic chamber shall surround the open jet test section in an acoustically absorbent chamber. The anechoic chamber door shall close off the test section from the model

prep. building and support a pressure difference sufficient to operate the open jet test section at  $M = 0.6$  at atmospheric pressure conditions. The acoustic treatment for the test cell walls and door shall be considered a permanent installation, although certain sections shall be removable for access. The acoustic treatment shall be durable enough to withstand ambient test cell conditions during normal operations and not obstruct normal operations. The acoustic treatment for the floor space surrounding the open jet test section cart shall be portable and to allow convenient installation and removal. The acoustic treatment on the floor of the anechoic chamber shall be designed to be adaptable and installed and removed within specified times to minimize facility down time. All acoustic treatment shall be heat and flame resistant.

### Criteria:

**Table 1.4.2.3.a LSWT Anechoic Chamber Criteria**

<b>Parameter</b>	<b>Requirement</b>
Standards	<i>TBD</i>
Acoustic Treatment	
Absorption Ratio	0.99
Cutoff Frequency, Hz	100
Material Type	<i>TBD</i>
Installation/Removal Time For Portable Sections	<i>TBD</i>
Operating Pressure Differential Across Walls	<i>TBD</i> , Aeroline Study
Design Pressure Differential Across Walls	<i>TBD</i> , Aeroline Study
Door Opening/Closing Speed	<i>TBD</i>

### **1.4.3 Tunnel Internal Systems**

**Definition:** The tunnel internal systems include all components internal to the stationary pressure shell provided for the purpose of controlling the air flow quality in the wind tunnel. Included systems are the turning vanes; heat exchanger; settling chamber liner and nozzle, high speed diffuser liner, honeycomb, turbulence attenuation screens, tunnel cleaning system and the compressor foreign object debris (FOD) system.

**Requirement:** Internal system elements shall maintain flow quality throughout the circuit such that test section flow quality requirements are satisfied.

#### **1.4.3.1 Turning Vanes**

**Definition:** Each 90-degree corner in the LSWT circuit is equipped with turning vanes to turn the direction of the mean flow for minimum corner dynamic pressure loss and highest possible flow quality. The turning vane system includes: (1) vertical turning vanes in corners 1, 2, 3, and 4; (2) attachment brackets, which are attached to mounting pads provided on the inside of the tunnel shell; and (3) personnel access to the turning vanes for maintenance and inspection.

**Requirement:** The turning vane cross sectional shape shall be optimized to maximize aerodynamic efficiency of the turning vane itself. Efficiency shall include, but is not limited to, complete turning of the flow in the corner at a minimum pressure loss and fully attached flow over the entire surface of the vane. The trailing edge of each turning vane shall be aligned to within 1-degree of the specified offset to the duct centerline axial direction. Each turning vane corner assembly shall be an integral unit complete with splitter vanes and access doors. Turning vanes sets #1 and #4 (downstream and upstream of the test section, respectively) shall be acoustically treated to reduce noise from the drive fan noise reaching the test section. It may be necessary to acoustically treat the turning vanes in corners #2 and #3 as well. The turning vanes shall be supported by the pressure shell by radial expansion type connectors.

**Criteria:**

**Table 1.4.3.1.a LSWT Turning Vane Criteria**

Parameter	Requirement
Standards	<i>TBD</i>
Allowable Pressure Loss	<i>TBD</i> (Airlines Study)
Gap to Chord Distance Ratio	<i>TBD</i> (Experimental Verification)
Flow Conditions At Entrance:	<i>TBD</i> (Airlines Study)
Dynamic Pressure (max.)	<i>TBD</i> (Airlines Study)
Turbulence Levels (max.)	<i>TBD</i> (Airlines Study)
Required Flow Quality At Exit:	
Turbulence Levels (max.)	<i>TBD</i> (Airlines Study)
Structural Design	
Design Standards	<i>TBD</i>
Design Safety Factors	<i>TBD</i>
Design Fatigue Life	Infinite
Allowable Deflections (max)	<i>TBD</i>
Natural Frequency (min)	<i>TBD</i> (Design Analysis)
Materials	<i>TBD</i>
Shape; Leading and Trailing Edge Treatment	<i>TBD</i>
Acoustic Treatment Materials	<i>TBD</i>

**1.4.3.2 Heat Exchanger**

**Definition:** The tunnel air is cooled by an an air to water heat exchanger located in the tunnel circuit. The physical location and configuration of the heat exchanger in the circuit is *TBD*. The function of the heat exchanger is to remove energy introduced by the fan and provide some temperature control. This work package includes the internal heat exchanger plus all associated supply and return piping, headers and expansion joints inside the tunnel. It also includes control valves, stabilizing tanks, immersion heaters (if required), and controls. Attachment brackets for the heat exchanger support structure, and circular fairings covering the gap between the inner diameter of the tunnel shell at the upstream and downstream ends are also included in this work package. It does not include the cooling tower, cooling tower controls, circulating pumps, or

cooling water piping outside the tunnel (Section 1.3.5). This work package also does not include tunnel penetrations (Section 1.4.1.3). The heat exchanger is divided into the following sub-elements: Modular Tube Bundle Assembly, Tube Bundle Support Structure, Supply and Return Manifolds, and Heat Exchanger Control System.

**Requirements:** The heat exchanger shall be sized to remove sufficient energy to limit the operating temperature to a maximum of ambient plus 30 degrees F, for all operating conditions. The heat exchanger must be designed for acceptable pressure losses and minimal air side flow disturbances. The flow quality requirements are specified below. The heat exchanger system shall contain features to control both the spatial and temporal uniformity of the temperature in the test section in order to meet specified flow quality requirements.

One such feature is to use alternating flow directions in adjacent tubes to improve temperature uniformity across the test section. Tradeoff studies are required in order to optimize the tube/fin geometry, to evaluate the need for elliptical shaped tubes to minimize flow disturbances as the air passes through the heat exchanger, and to evaluate the number of cooling passes required. Consideration shall be given to accessibility of the heat exchanger hardware for maintenance and repair. Also, to facilitate maintenance and repair, the heat exchanger coil shall be designed and built as modular units. The heat exchanger design must be compatible with the cleaning system proposed in Section 1.4.7 The heat exchanger must fit within the geometrical constraints given with supply and return headers and as much support equipment as possible located outside the flow boundary.

The heat exchanger support frame shall provide a rigid structure for mounting the tube bundle modules. The structural stiffness of the support frame and tube bundle assembly shall be sufficiently large to avoid any potential first mode flow excitation frequencies. Aerodynamically shaped fairings shall be used, where practical, to minimize flow disturbances. Consideration must be given to the thermal expansion throughout the operating range, in particular the differential expansion between the coil and the support structure.

The cooling water system shall contain the necessary expansion/surge tanks, flexible joints, throttling valves, automatic aeration equipment, automatic drainage/freeze protection system and other features to guarantee safe and reliable operation. The internal cooling water system connects to the forced draft cooling tower water distribution system described in Section 1.3.4.

Special considerations must be made to the overall system reliability requirements. Predictive maintenance techniques and other reliability enhancement features, such as redundant instrumentation, shall be used, when required to minimize unscheduled downtime. The control system shall be compatible with the integrated controls and data acquisition requirements, described in Section 1.4.5.2.

**Criteria:**

Table 1.4.3.2.a LSWT Heat Exchanger Criteria

Parameter	Requirement
Standards: <i>TBD</i> -	Design
Total Heat Removal Capacity:	<i>TBD</i> , Ref.: Aerolines Study
Air Stagnation Pressure:	75 psia
Total Air Mass Flow Rate:	<i>TBD</i> - Studies
Total Heat Exchanger Flow Area:	<i>TBD</i> - Design
Maximum Air Temperature Entering Coil:	<i>TBD</i> - Design
Maximum Air Side Pressure Drop Across Coil:	<i>TBD</i> - Design
Minimum Water Flow Rate:	<i>TBD</i> - Design
Minimum Water Temperature Entering Coil:	<i>TBD</i> - Design
Maximum Water Temperature Exiting Coil:	<i>TBD</i> - Design
Maximum Water Pressure Loss:	<i>TBD</i> - Design
Maximum Waterside Operating Pressure:	<i>TBD</i> - Design
Heat Exchanger Efficiency:	
At Start:	<i>TBD</i> - Design
Nominal:	<i>TBD</i> - Design
Before Required Cleaning:	<i>TBD</i> - Design
Waterside Fouling Factor:	
At Start:	<i>TBD</i> - Design
Nominal:	<i>TBD</i> - Design
Before Required Cleaning:	<i>TBD</i> - Design
Airside Fouling Factor:	
At Start:	<i>TBD</i> - Design
Nominal:	<i>TBD</i> - Design
Before Required Cleaning:	<i>TBD</i> - Design
Air Temperature Requirements:	
Spatial:	See Tables 1.4.a & Table 1.4.d
Temporal	<i>TBD</i> - Studies
Flow Quality Requirements:	See Table 1.4.d
Fin/Tube Geometry:	<i>TBD</i> - Experimental Tests
Heat Exchanger Materials:	<i>TBD</i> - Design

### 1.4.3.3 Settling Chamber Liner and Nozzle

**Definition:** The settling chamber liner forms the aerodynamic surface of the LSWT from the entrance of the wide angle diffuser to the test section. This package includes mounts for flow conditioning components located in the settling chamber as well as structural framing required to mount the liner to pressure vessel shell attachment points.

**Requirement:**

The settling chamber liner shall withstand all structural and aerodynamic loads over the entire LSWT operating envelope. The settling chamber liner shall have penetrations through it on either side of each honeycomb and screen element sections. The penetrations are required for personnel access for routine maintenance, inspection, repairs and cleaning of the settling chamber flow conditioning elements. The accesses shall not protrude significantly into the flow stream, such that flow disturbances are created. The accesses shall not cause the test section flow quality to be out of tolerance.

The wide angle diffuser shall include a screen or other suitable pressure drop device sufficient to maintain fully attached flow inside the diffuser. The contraction nozzle contour shall be optimized for quality flow in the test section.

**Criteria:**

- Standards: *TBD*
- Geometry: *TBD, Ref.: Aeroline Study*
- Materials: *TBD, Design*
- Manufacturing Tolerances: *TBD, Design*  
   Machining Requirements  
   Surface Finish Requirements

**1.4.3.4 High Speed Diffuser Liner**

**Definition:** The high speed diffuser forms the flow surface from the exit of the isolation valve downstream of the test section to entrance of the conical diffuser section, providing a transition from rectangular to round cross section.

**Requirement:** The geometry of the high speed diffuser shall be optimized for maximum static pressure recovery. A maximum of 5.5 degree total expansion angle is recommended.

**Criteria:**

- Standards: *TBD*
- Geometry: *TBD, Ref.: Tunnel Aerolines*
- Materials: *TBD, Design*
- Manufacturing Tolerances: *TBD, Design*
- Machining Requirements: *TBD, Design*
- Surface Finish: *TBD, Design*

### 1.4.3.5 Honeycomb

**Definition:** The honeycomb is used primarily to attenuate lateral and vertical components of flow turbulence to a level required to meet the flow quality requirements in the test section.

**Requirement:** The honeycomb shall be sized to reduce lateral and vertical turbulence levels and flow angularity to a level required to meet the test section flow requirements (See Table 1.4.d). The honeycomb structure shall also be required to support aerodynamic loads encountered in any portion of the LSWT operating envelope. Personnel access to either side of the honeycomb is required for routine inspections, cleaning, repairs, and maintenance. The honeycomb support frame shall provide a rigid structure for mounting the honeycomb. The structural stiffness of the support frame assembly shall be sufficiently large to avoid any potential first mode flow excitation frequencies. Aerodynamically shaped fairings shall be used, where practical, to minimize flow disturbances. Consideration must be given to the thermal expansion throughout the operating range.

**Criteria:**

- Standards: *TBD*
- Flow Quality: *TBD, Aeroline Study*
- Aerodynamic Loads: *TBD, Aeroline Study*
- Honeycomb Geometry:
  - Cell Size: *TBD, Design*
  - Thickness: *TBD, Design*
  - L/D Ratio: *TBD, Design*
- Honeycomb Material: *TBD, Design*
- Honeycomb Support Structure Design: *TBD, Design*
- Allowable Pressure Drop: *TBD, Aeroline Study*

### 1.4.3.6 Turbulence Attenuation Screens

**Definition:** Turbulence screens reduce the longitudinal level of flow turbulence to a level required to meet test section flow quality requirements. The number of screens, spacing, mesh and wire sizes will be determined primarily on turbulence reduction basis. The screen mounting method, minimum size of screen wire, and to some degree, the screen mesh size will be determined by aerodynamic loads considerations.

**Requirement:** Open area for the screen in the settling chamber shall be larger than 57%. The spacing of the screens in the settling chamber shall be such that maintenance personnel can access either side of the screen to perform routine inspections, cleaning, repairs, and

maintenance. The personnel access shall not require the removal of any screens. The spacing shall also allow for the rigid installation and erection of the tunnel cleaning and inspection system. The screen support frame shall provide a rigid structure for mounting the screens. The structural stiffness of the support frame assembly shall be sufficiently large to avoid any potential first mode flow excitation frequencies. Aerodynamically shaped fairings shall be used, where practical, to minimize flow disturbances. Consideration must be given to the thermal expansion throughout the operating range.

**Criteria:**

- Standards: *TBD*
- Screen Size, Porosity, and Effectiveness: *TBD, Aeroline Study*
- Aerodynamic Loads: *TBD, Aeroline Study*
- Allowable Pressure Drop: *TBD, Aeroline Study*
- Screen Material: *TBD, Design*
- Acceptible Screen Joint: *Butt Welds Only*
- Number of Screens: *TBD, Plus Provisions for 1 Future Screen*

**1.4.3.7 Tunnel Cleaning System**

**Definition:** The tunnel cleaning system will provide a means of cleaning all of the internal components of both wind tunnels. These components include (but are not limited to) the turning vanes, heat exchanger, screens, honeycomb, fan blades, and baffles (if required).

**Requirements:** The cleaning system shall consider access to all elements requiring routine inspection and cleaning. The cleaning system shall be such that it can be removable or at least retracted out of the flow stream during tunnel operation. The cleaning system shall be able to be installed in under 15 minutes at any location and removed within 15 minutes at any location. The cleaning system shall not leave any substantial residue or fluid in the tunnel circuit at the conclusion of a cleaning evolution.

Criteria: *TBD*

**1.4.3.8 Compressor Foreign Object Debris (FOD) Screen**

**Definition:** A screen section on or just upstream of the turning vane set # 2 that protects fan blades from debris. This screen section, a coarse mesh screen, may or may not extend the full height of the cross section.

**Requirement:** The foreign object debris (FOD) screen shall be designed based on the expected sizes and momentums of debris from failed models and tunnel components. Simultaneously, the FOD shall be designed for minimum flow total pressure loss.

**Criteria:**

- Standards: *TBD*
- Allowable Pressure Loss *TBD*, Aeroline Study
- Projectile Definition:
  - Projectile Sizes: *TBD*
  - Projectile Shapes: *TBD*
  - Projectile Weights: *TBD*
  - Max Kinetic Energy To Be Absorbed (ft-lbs) *TBD*
- Screen Material, Mesh Size, Wire Size, and Porosity *TBD*, Design
- Acceptable Screen Joints: Butt Weld Only
- Screen Absorption Capability: *TBD*

#### 1.4.4 Compressor And Drive System

**Definition:** The LSWT Compressor and Drive System provides the shaft power and the compressor which produces LSWT air flow. The primary components are the motor(s), motor controls, axial compressor (fan), and drive system auxiliaries. The motor feed current is provided by the yard Electrical Power System (Section 1.1.4.).

The motor(s) interface with the Drive Motor Controls (1.4.4.2) at the closest physical connection point to the motor(s). The drive motor foundations are included in 1.2.2.3, LSWT/TSWT Drive Building. The axial compressor rotor will interface to the drive motor at the parting surface of a coupling flange closest to the LSWT pressure shell. A common flange configuration is required for all drive motor and compressor couplings, if feasible. The coupling hardware (bolts, pins, etc.) are included in the 1.4.4.1. and 1.4.4.3 definition. The motor(s) and compressor includes *TBD* type bearings to support each end of their respective rotor shafts. The interface surface between bearings and shafts is defined as the surface of rotation, i.e. the rotating shaft is part of the shaft and the stationary bearing surface is included in the bearing package. The Compressor and Drive System includes the following sub-elements: 1.4.4.1. Drive Motor(s), 1.4.4.2. Drive Motor Controls, and 1.4.4.3. Axial Compressor and Case, and 1.4.4.4 Drive System Auxiliary Systems.

**Requirement:** High value equipment protection and reliability of total system performance are the major design requirements. Common design features and interchangeable equipment shall be used to the maximum extent practical throughout the NWTC. The design Mach/total pressure

point coupled with maximum Mach Number required will determine the design pressure ratio for the compressor. The acoustic requirements are expected to be a major factor in the compressor (fan) design, tending to push for low tip mach number, highly uniform compressor inflow, and greater spacing than traditional between rotating blades and non rotating elements (i.e. stators, vanes, supports, etc.). The Compressor and Drive System shall be designed as an integrated system with trade studies which consider design risk (assured reliable life cycle operation over the full range of test conditions required for LSWT), energy efficiency and reduced acoustic levels as key criteria in the determination of specific design requirements for its sub-systems and components.

To the maximum extent practical, the components and subsystems used throughout the NWTC shall be of common design and interchangeable. The physical location of all equipment shall be such to facilitate maintenance and handling functions. Unless impractical, all bearings and couplings in 1.4.4.1 and 1.4.4.3 are required to be physically and functionally interchangeable. All bearings shall be designed with a means of continuing to provide lubrication and thus allow safe shutdown in the event of a lube system failure. The bearings are required to operate at the full range of LSWT conditions without loss of oil into the tunnel.

All drive train elements are required to transmit the full overload rating of the drive system on a routine basis. In addition, all drive train elements shall be capable of withstanding maximum torque load for emergency stops and/or maximum acceleration with no deleterious effects. The couplings and mating interface surfaces are to be of common design for all motor interfaces. The drive train / coupling design is required to allow for the thermal expansion, relative movement and vibrations between the drive motor(s) and LSWT compressor.

Health monitoring and diagnostic instrumentation will be provided by the Predictive Maintenance System 1.4.5.5. Provisions for the integration of the 1.4.5.5. instrumentation shall be made during the detailed design of each appropriate component of 1.4.4. and included in the 1.4.4. requirements.

**Criteria:**

- |   |                   |
|---|-------------------|
| • Standards:                                  | <b><i>TBD</i></b> |
| • Sync Speed                                  | <b><i>TBD</i></b> |
| • Shaft Power vs. RPM                         | <b><i>TBD</i></b> |
| • Power Ramp Rates                            | <b><i>TBD</i></b> |
| • Drive Power Design Point                    | See Table 1.4.a   |
| • Maximum System Acceleration Point (RPM/sec) | <b><i>TBD</i></b> |
| • Maximum System Deceleration Rate (RPM/sec)  | <b><i>TBD</i></b> |
| • Overall Drive System Reliability            | <b><i>TBD</i></b> |

#### 1.4.4.1 Drive Motor(s)

**Definition:** The drive motor(s) provide the compressor shaft power to establish and maintain aerodynamic flow in the LSWT. The drive motor(s) include the following sub-elements: Rotor(s), Bearings, Couplings, Stator(s), and Cooler(s).

**Requirement:** The motor sizing and design shall be defined by the LSWT performance requirements and projected compressor design performance. The LSWT motor(s) shall be of common design, physically and functionally interchangeable to the extent practical with other large motors in the NWTC. Major components shall be interchangeable to the extent practical based on Life Cycle Cost considerations. The motor, drive shaft, building and support equipment shall provide the ability to remove the main drive motor from the LSWT Main Drive Train, install a replacement motor and reestablish drive capability within 24 hours.

**Criteria:**

• Standards:	<i>TBD</i>
• Number and size of motors	<i>TBD</i>
• Voltage	<i>TBD</i>
• Output power vs. RPM	<i>TBD</i>
• Input power vs. load	<i>TBD</i>
• Continuous Duty Rating at Design Power Point	1.05
• Intermittent Duty Rating	1.20 of Continuous Duty Rating
• Duration of Intermittent Duty	1 hour Synchronous Speed
• Bearing Type	<i>TBD</i>
• Cooling System Capacity (hp)	<i>TBD</i>

#### 1.4.4.2 Drive Motor Controls

**Definition:** The drive motor controls provide the variable frequency start system and sub synchronous speed control system for the LSWT Drive Motor(s), 1.4.4.1. The major components of the system includes the switch gear, harmonic filters and redundant power conditioning and directly related equipment. A major portion of the equipment may be located outdoors in the Station No. 1 area adjacent to the main substation (Section 1.1.4).

The Drive Motor Controls system receives input power from the power conversion equipment in the Yard Electrical Power System, Section 1.1.4. The power input interface is at the first

physical connection point inside the initial enclosure(s). The output interface is the physical connection to the motor(s). The demand/set point control input to this equipment comes from Section 1.4.5.2 with the output signal being routed to the appropriate location for input to this equipment. The drive motor controls includes the following sub-elements: Switch Gear, Harmonic Filters, Power Conditioning Equipment, and Related Equipment.

**Requirement:** The primary design requirement shall be to accelerate to any desired speed above 5% of synchronous speed and maintain that speed  $\pm 1$  rpm indefinitely. The physical architecture shall provide for a flexible system which is sufficiently interconnected and equipment positioned to allow maximum ability to continue test operations during equipment repair and maintenance periods. Consideration of collateral damage minimization from potential failure modes shall be design criteria for equipment location and physical arrangement. A robust design, reliable and efficient operation and long term assured technical and spares support are significantly more important than minimum initial cost. All equipment must be provided with environmental protection and sufficient environmental conditioning consistent with its location to ensure reliable operations and most economical life cycle cost.

**Criteria:**

- |   |            |
|---|------------|
| • Standards:  | <i>TBD</i> |
| • Ramp time to any speed                              | <i>TBD</i> |
| • Speed stabilization time                            | <i>TBD</i> |
| • Power requirement                                   | <i>TBD</i> |
| • Number and size of components                       | <i>TBD</i> |
| • Speed Control Accuracy<br>(Above Synchronous Speed) | +/- 1 RPM  |
| • Speed Control Accuracy<br>(Below Synchronous Speed) | <i>TBD</i> |

#### 1.4.4.3 Axial Compressor and Case

**Definition:** Provides the LSWT primary axial flow compressor shaft; structural mounting discs for the rotating blades; the rotating blades; non-rotating blades, supports and vanes; pressure shell section at the compressor; flanges on the compressor shell for attachment to the rest of the pressure shell; all elements of the drive shaft (except motor elements); and all directly related fairings, seals and equipment. The blade and hub design shall readily allow repair and blade replacement to support high productivity. Provides 120% spare blades, 110% of the spares are to be manufactured after performance acceptance of the compressor installed in the LSWT.

The compressor nacelle provides the aerodynamically contoured shell (teardrop shape) around the compressor hub and a symmetric airfoil fairing is provided around the primary drive shaft.

This fairing is needed to reduce separation, acoustic disturbances and shaft aerodynamic loads. The drive shaft fairing is expected to attach to the pressure shell at the drive shaft penetration and extend through the turning vanes to the nacelle fairing. The primary supports of the compressor both forward and aft of the rotor blades constitute the principal load path for the compressor loads. The aerodynamic and structural requirements for these components are major factors in the compressor design effort. The required seals and directly related hardware to make the nacelle an effective aerodynamic shape are included.

The rotating portions of the nacelle attach to the rotor shaft and the interface is at the removable joint closest to the center of rotation with all fasteners provided with the fairings under this work package. The non-rotating portion of the nacelle will attach to the supports and provide the center body attachment for the stators/EGVs. The interface with movable or adjustable components will be at the removable joint which separates the movable surface from the stationary elements.

The compressor case provides the pressure shell, structural mounting rings, stators, and support vanes for the compressor. The compressor case interfaces with the pressure shell at mating flanges oriented perpendicular to the compressor axis of rotation. The mating surface flatness and alignment specifications shall be specified by pressure shell design of Section 1.4.1.3.

The stators/vanes interface with the nacelle, at the movable interface to the fixed surface, with all mounting hardware and fittings are provided by this work package. This package provides all design provisions for integration and installation of the position indicators and structural instrumentation for the components included herein. The sensors and related instrumentation for the blade position, rotor speed and other control parameters will be provided by Section 1.4.5.4. and integrated into the LSWT Process Instrumentation System. The axial compressor/case includes the following sub-elements: Rotor shaft/hub, all drive shaft components except those with the drive motors, Rotor blades, Rotor bearings, Bearing supports, Seals, Stators and vanes, and Fairings.

**Requirement:** The design and integration of the Axial Compressor and Case elements must accomplish the acoustic, aerodynamic and energy efficient requirements and objectives of the LSWT. They shall also provide maintenance and operational concepts which support long term productivity and life cycle cost objectives. Fail-operate provisions shall be incorporated in all controllable surfaces to the extent practical. Fail-safe provisions shall be provided. All adjustable and controllable components shall include sufficient position indicators to record compressor configuration during all operation via the LSWT Process Instrumentation, 1.4.5.4.4. Required instrumentation provisions for health monitoring and Predictive Maintenance System inputs shall be interfaced with 1.4.5.5. Requirements for low turbulence and acoustic testing demand greater than normal care in the aerodynamics contouring of all air-stream surfaces and fairings. The design and fabrication approach are likely to be affected by the need for tolerances which are unusually stringent.

The compressor case shall be able to contain the rotor blades in the event of a catastrophic failure as well as meet the pressure requirements of the pressure shell. The compressor case shall meet the pressure shell requirements specified in Section 1.4.1.3.

Maintenance and accessibility require special considerations to meet productivity requirements. The compressor case section shall provide a compressor access maintenance door, which will allow for rapid access to the rotor and stator blades. The access shall be sufficient to allow for removal and installation of rotor and stator blades. The access door is required to operate at all pre and post operational shell temperatures and shall open or close in no more than 15 minutes on a routine basis. Removable hatches are required directly over the compressor bearings of sufficient size to allow bearing removal. Fixtures and tools to support bearing assembly and replacement are included.

This work package will provide five (5) instrumented blades which have been calibrated to provide maximum bending and torsion stresses. The instrumentation provisions to provide eight channels of strain gage data to the tunnel shell are also included in this work package. These data channels will be interfaced with 1.4.5.5. (Predictive Maintenance System) external to the compressor shell. Only limited physical interface with the nacelles and supports, and the stators/EGVs are expected but seals, critical tolerances and integral design requirements for compressor performance will require extensive interface during the design and installation of the compressor. The lubrication and cooling requirements shall be provided with the interface point at the bearing penetrations for lift/lube oil connections.

The drive shaft shall not have any first mode frequencies that are less than at least twice the maximum shaft rotational speed.

**Criteria:**

• Standards:	<b>TBD</b>
• Required Performance (Airflow, pressure ratio and stall margins)	<b>TBD</b>
• Bearing loads and torques	<b>TBD</b>
• Operating temperatures	<b>TBD</b>
• Number & spacing of primary elements (rotor blades, stators/vanes, support struts)	<b>TBD</b>
• Acoustic levels	<b>TBD</b>
• Materials:	<b>TBD</b>
• Pressure Shell	See Table 1.4.1.3.a

#### 1.4.4.4 Drive System Auxiliary Systems

**Definition:** This section includes the ancillary support systems required for the compressor drive system. The subsystems are the bearing lubrication sub-system, and the drive system cooling

sub-system. The bearing lubrication sub-system includes all pumps, pump motors, supply and return piping, filters, headers, expansion joints, valves, instruments, tanks, immersion heaters, coolers, motor starters, switchgears, and controls. The interfaces are at the compressor shell, and at each pedestal for the bearings external to the tunnel shell (for the oil supply and return), and the power connection to the switchgear. The drive system cooling sub-system consists of all headers, valves, supply and return piping, filters, controls, instruments, and boost pumps (if required). The sub-system provides cooling to the bearing lubrication sub-system, as well as the tunnel drive motors. The drive system cooling sub-system interface with the NSWC cooling system (Section 1.3.4) is **TBD**.

**Requirements:** The bearing lubrication sub-system shall be sized to provide at least 150% of the total manufactures required lubrication flow for all elements connected to the system. The system configuration (i.e. multiple dedicated units, single pump with single supply/return headers, etc.) is **TBD**. Consideration shall be given to the accessibility of all components in the bearing lubrication sub-system for maintenance and repair. Special considerations must be made to the overall system reliability requirements. Predictive maintenance techniques and other reliability enhancement features, such as redundant instrumentation, shall be used, when required to minimized unscheduled downtime. The control system shall be compatible with the integrated controls and data acquisition requirements, described in Section 1.4.5.2.

The drive system cooling sub-system shall be sized to provide at least 150% of the total manufactures required cooling flow for all elements connected to the system. The system configuration is **TBD**. Consideration shall be given to the accessibility of all components in the bearing lubrication sub-system for maintenance and repair. Special considerations must be made to the overall system reliability requirements. Predictive maintenance techniques and other reliability enhancement features, such as redundant instrumentation, shall be used, when required to minimized unscheduled downtime. The control system shall be compatible with the integrated controls and data acquisition requirements, described in Section 1.4.5.2.

### Criteria:

#### Bearing Lubrication Sub-system Requirements

• Design Pressure	<b>TBD</b>
• Maximum Design Temperature	<b>TBD</b>
• Minimum Design Temperature	<b>TBD</b>
• Maximum Flow Rate	<b>TBD</b>
• Lubrication Oil Type	<b>TBD</b>
• Total Storage Capacity	<b>TBD</b>
• Total Number of Pumps	<b>TBD</b>

**Drive System Coling Sub-system Requirements**

- Design Pressure *TBD*
- Maximum Design Temperature *TBD*
- Minimum Design Temperature *TBD*
- Maximum Flow Rate *TBD*
- Total Storage Capacity *TBD*
- Total Number of Pumps *TBD*

**1.4.5 Electrical, Controls And Data Acquisition System****1.4.5.1 Low Voltage Electrical System**

**Definition:** Provides the low voltage electrical system for the LSWT.

**Requirement:** The 480 volt and lower electrical systems including secondary switchgear and load centers; 480 volt motor control centers, power distribution panels; DC system equipment with batteries, chargers, distribution panels, and motor control; and wiring and cable tray/conduit systems shall be provided. Also included is the raceway complex for the control systems and the data acquisition systems.

**Criteria:** *TBD*

**1.4.5.2 Controls System**

**Definition:** Controls system includes all electrical/electronic components, cabling, and software necessary to control tunnel processes and subsystems listed below for the LSWT. This section does not include sensors, actuation devices, or power sources/controllers for the actuation devices.

**LSWT Control Processes and Subsystems**

Compressor speed	Compressor blade angle
Tunnel pressure/vacuum	Tunnel humidity
Tunnel temperature	Test section side walls
Test section isolation	Model attitude
Model engine	Model control surfaces
Pressure probe	Acoustic probe
Model propulsion	Interlocks

**Requirements:** Integrated controls and test data acquisition systems shall be utilized in the LSWT. They shall provide automated execution of test sequences, automated start up and shut down of auxiliaries, and comprehensive tunnel process monitoring with diagnostics. The system shall be designed to accommodate any single point of failure without facility damage or personnel harm. Sensors supplying test data and process data shall be shared where practical and pre-run calibrations are utilized in addition to selective redundant sensors to maximize tunnel availability. Separate control rooms and control systems for each tunnel are specified to minimize down time and eliminate possible security issues. Operator interfaces shall consist of workstations (x-window terminals) with uniformity of displays and operational procedures between tunnels. Operators shall have three levels of control authority which consist of coordinated control of tunnel processes, control of set points to individual processes, and control of actuation devices.

**Criteria:**

- |   |            |
|---|------------|
| • System availability                                 | <i>TBD</i> |
| • Control ranges of processes                         | <i>TBD</i> |
| • Accuracies of processes at steady state conditions  | <i>TBD</i> |
| • Maximum rates of change of processes                | <i>TBD</i> |
| • Transient responses and settling times of processes | <i>TBD</i> |

#### 1.4.5.3 Data Acquisition System

**Definition:** The data acquisition system includes the following sub-elements:

- Tunnel Parameter Data System
- Data Acquisition Control Processor
- Data Processing Workstations
- Data Analysis Workstations
- Development and Simulation
- Data Archive File Servers
- Data Analysis Rooms
- Communications
- Test Instrument Cart
- Test Static Data System
- Dynamic Pressure Data System
- Hot Wire Anemometer Data System
- Acoustic Data System

## Tunnel Parameter Data System

**Definition:** This system acquires data from various locations around the tunnel circuit. Measurements are predominantly temperatures, dew point, pressures, and positions needed for test or control functions.

**Requirements:** This tunnel parameter data system shall acquire the data, compute engineering units, and coefficients, perform some limit checking and alarming, and make the data available via high speed networks to the tunnel control and facility management processors. Trend and historical performance data are archived for later analysis. Data are also passed to the data acquisition control processor for synchronization with the test or research data and for real-time display.

Most pressure data is acquired through an electronic pressure scanning system (ESP) with a capability of scanning up to 1000 pressure channels. The data acquisition unit shall have the capability of scanning up to 256 analog channels and 24 general purpose digital channels. The data acquisition unit shall allow programmable settings for filter selections and variable gain settings on an individual channel basis.

### Criteria:

Data Acquisition Unit: **TBD**

#### Active Filters:

Up to 4 programmable settings per channel - ranges: **TBD**

Filter Characteristics: 4 pole Butterworth or Bessel - **TBD**

Signal Conditioning:

Channel Count Requirements: **TBD**

Variable Transducer Supply Excitation Voltage Range: **TBD**

Bridge Completion Characteristics: **TBD**

Modes Supported: strain gage, thermocouple, RTD

#### Amplifier characteristics:

Amplifier Per Channel

Input Impedance: greater than 10 megohm

Common Mode rejection: 120 db minimum

Gain Ranges: 12 minimum, covering 5 mv. up to 10 volt, FS

#### Additional Features:

Programmable Sampling Rate: **TBD**

Automatic Calibration Capability: **TBD**

Automatic Zero Capability: **TBD**

Overall System Accuracy and Noise: **TBD**

**Computer Subsystem:**

Standards: appropriate federal open systems standards - *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. - *TBD*  
Bus Architecture: *TBD*

**Peripherals:**

Fixed Disk: Size, transfer rate, format - *TBD*  
Removable Disk: Size, transfer rate, format - *TBD*  
Optical Disk: Size, transfer rate, format - *TBD*  
Archive Tape: Size, transfer rate, format - *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF,  
meeting appropriate standards for networking, portability,  
and other features - *TBD*

Custom designed data acquisition, calibration, control, and real-time display software  
appropriate for meeting the acquisition and display requirements noted above - *TBD*

**Data Acquisition Control Processor**

**Definition:** This system acquires test measurements from the test section or a cart bay area and the tunnel parameters processor.

**Requirements:** The data acquisition control processor shall acquire test measurements from the test section or cart area via a high speed fiber optics network from processors on the model cart. Information from the test section shall be synchronized with the tunnel parameter information, reduced to engineering units and coefficients, and passed through high speed networks to other data processing, analysis, and control systems. This processor shall also provide real-time display to the data acquisition system operator's console. This processor is required to handle the sequencing of all data acquisition related processes when commanded by the operator or by the facility management processor and when test conditions are achieved. This processor also alerts the facility management processor when data has been acquired so that test conditions can be set for the next test point.

**Criteria:****Computer Subsystem:**

Standards: appropriate federal open systems standards - *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. - *TBD*  
Bus Architecture: *TBD*

**Peripherals:**

Fixed disk: Size, transfer rate, format - *TBD*  
Removable Disk: Size, transfer rate, format - *TBD*  
Optical disk: Size, transfer rate, format - *TBD*  
Archive Tape: Size, transfer rate, format - *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF,  
meeting appropriate standards for networking, portability,  
and other features - *TBD*

Custom designed data acquisition, calibration, control, and real-time display software  
appropriate for meeting the acquisition and display requirements noted above - *TBD*

**Data Processing Workstations**

**Definition:** These workstations receive test data for the data acquisition processor via a high speed network.

**Requirements:** The data processing workstations are required to process the test data on-line in near real-time for the test engineer's test console as well as other stations. Data shall be represented though a high end graphical user interface that will present data in a flexible, easy format that can quickly be changed by the engineer.

Criteria:

## Workstation Requirements:

Standards: appropriate federal open systems standards *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle Time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*  
Bus Architecture: *TBD*

## Peripherals:

Fixed Disk: Size, transfer rate, format - *TBD*  
Removable Disk: Size, transfer rate, format - *TBD*  
Optical disk: Size, transfer rate, format - *TBD*  
Archive Tape: Size, transfer rate, format - *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

## Software:

Real-time Posix Operating System with X Window/MOTIF,  
meeting appropriate standards for networking, portability,  
and other features *TBD*

Custom designed real-time display software appropriate for meeting  
the acquisition and display requirements noted above *TBD*

**Data Analysis Workstations**

**Definition:** These workstations provide near real time and off-line analysis capability.

**Requirements:** These workstations shall have high end graphics capability that can be used to readily compare current data with previous test conditions stored on the data archive file server. These displays shall be located near the test engineer's console and can be networked to the data analysis rooms.

## Workstation Requirements:

Standards: appropriate federal open systems standards *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*

Memory Cycle time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*  
Bus Architecture: *TBD*

**Peripherals:**

Fixed Disk: Size, transfer rate, format *TBD*  
Removable Disk: Size, transfer rate, format *TBD*  
Optical Disk: Size, transfer rate, format *TBD*  
Archive Tape: Size, transfer rate, format *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF meeting appropriate standards for networking, portability, and other features *TBD*

Custom designed data analysis software appropriate for meeting the acquisition and display requirements noted above *TBD*

Data Analysis Software Tools - Software for signal processing, visualization, data reduction, database management, and other features typically required for data analysis.  
Final Requirements *TBD*

**Development And Simulation Processors**

**Definition:** The development and simulation processors are available to support development and operations functions without interfering with the daily operations of the tunnels.

**Requirements:** Functions that shall be supported by the development and simulation processors include data acquisition systems software development, controls systems software development, simulation, documentation support, hardware and software system checkout, test preparation, and software configuration control. One processor shall be provided for DAS support, one for controls, and a small file server for documentation and administrative services. These computers shall also be configured in such a fashion that they can serve as backup processors for other processors on the control room network.

Criteria:

## Computer Subsystems:

Standards: appropriate federal open systems standards *TBD*

Clock Rate: *TBD*

Processing Speed: *TBD*

Memory Cycle time: *TBD*

Memory Size: *TBD*

Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*

Bus Architecture: *TBD*

## Peripherals:

Fixed Disk: Size, transfer rate, format *TBD*

Removable Disk: Size, transfer rate, format *TBD*

Optical Disk: Size, transfer rate, format *TBD*

Archive Tape: Size, transfer rate, format *TBD*

Hard Copy Units: *TBD*

X Terminal Characteristics: *TBD*

Network Interfaces and Packet Transfer Rates: *TBD*

## Software:

Real-time Posix Operating System with X Window/MOTIF, meeting appropriate standards for networking, portability, and other features *TBD*

Custom designed data acquisition, control, and real-time display software appropriate for meeting the acquisition and display requirements noted above *TBD*

Computer Aided Software Engineering tools:

Software to manage the design, integration, testing, and life cycle support for the data acquisition, control, data analysis, and other software required to operate and maintain all computer systems within the test facility. Final Requirements *TBD*

Configuration Management Tools:

Software tools to track, document, and manage configuration changes to software, hardware, cabling, instrumentation, etc. associated with the life cycle support of the facility.

Final Requirements *TBD*

**Data Archive File Servers**

Definition: These processors are the repository for test data as it is being acquired.

**Requirements:** Test data shall be stored on the data archive file servers. Tunnel process control data shall also be archived on a separate server for post test analysis. Previous test configuration data or theoretical predictions shall reside on this archive system so that they may be called up for analysis and comparison with the current test. Files shall be maintained in a secure environment to provide access only as required. Optical disk storage shall be provided for archiving large volumes for static and dynamic data, and high speed printers shall be provided.

**Criteria:**

**Data Archive Subsystem Requirements:**

Standards: appropriate federal open systems standards *TBD*

Clock Rate: *TBD*

Processing Speed: *TBD*

Memory Cycle Time: *TBD*

Memory Size: *TBD*

Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*

Bus Architecture: *TBD*

**Peripherals:**

Fixed Disk: Size, transfer rate, format *TBD*

Removable Disk: Size, transfer rate, format *TBD*

Optical Disk: Size, transfer rate, format *TBD*

Archive Tape: Size, transfer rate, format *TBD*

Hard Copy Units: *TBD*

X Terminal Characteristics: *TBD*

Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Posix Operating System with X Window/MOTIF, meeting appropriate standards for networking, portability, and other features *TBD*

Configuration management and data base management tools as appropriate for the maintenance and archiving of large data sets of research and control system data. Database management software shall meet appropriate national standards Final Requirements: *TBD*

**Data Analysis Rooms**

**Definition:** Two rooms will be provided adjacent to the main control room for use by visiting test personnel during preparation, testing, and limited post test analysis.

**Requirements:** Both data analysis rooms shall be networked to the cart areas, the test section, and the main control room; however, each data analysis room shall be capable of isolation for

classified tests so that only appropriate networks are active to support setup in a model preparation area or test section. Each analysis room shall have a file server for data archiving and analysis as well as several workstations and X terminals to support real-time data display, and analysis during setup, calibration, and checkout prior to tunnel entry. Video projection systems shall also be provided for displaying real-time or video from the test section.

**Criteria:**

Video Projection System Requirements:

Number of Display Stations: *TBD*

Size of Display Stations: *TBD*

Video Control System Requirements: *TBD*

Requirements for Video Integration on X terminals: *TBD*

See appropriate sections included herein for X terminal, file server, data analysis workstations, and other requirements.

**Communication Networks**

**Definition:** The communications networks are the high speed fiber optics networks that will be used extensively throughout the system.

**Requirements:** Since the system architecture uses a tiered, distributed system approach, communications networks will play a key role during systems operations. The proposed system shall offer support for LAN/Ethernet 802.3, FDDI, IEEE-488, RS 232/422, reflective memory fiber optic systems, and other technologies appropriate at the time of construction.

**Criteria:**

Standards: appropriate federal open systems standards that are applicable to networks - *TBD*

Reflective Memory Network Subsystem:

Transmission Media: *TBD*

Transfer rates: *TBD*

Number of Nodes: *TBD*

Bus architecture and interface for Nodes: *TBD*

Memory per Node: *TBD*

LAN/Ethernet 802.3 Requirements:

Number of Nodes: *TBD*

Transmission Media: *TBD*

Packet Transfer Rates: *TBD*

Other Network Requirements: *TBD*

## Test Instrumentation Cart

**Definition:** Each test cart contains a completely stand alone integrated data acquisition and control system.

**Requirements:** It is anticipated that the system will rely heavily on emerging VME, Futurebus, and VXI technology. A lower level control and data bus shall be provided so that various systems on the cart will have access to the same transducer inputs for control functions as well as test measurements where practical. Data shall be patched from the model to a patch panel for easy model setup and checkout. A fiber optics network link shall also be provided to the model for any on-board instrumentation. Signal conditioning shall be provided by this data system or, in some cases, by ancillary equipment for unique instrumentation. A higher level local area network (LAN) fiber optics communications bus connects the various processors on the cart to allow exchange of processed information. The static DAS, the dynamic DAS, and model attitude control systems shall remain as permanent systems on the cart, but additional systems to provide model engine simulator or high pressure air control, model surface control, probe control, or acoustic dynamic data acquisition can be installed as required. When these systems are added to the cart, they shall be connected to the data bus and inter-processor LAN communications bus which allows them to be integrated and controlled by software. Workstations and X terminals connect to the LAN to support the cart in the model build-up bay area.

All calibration, model attitude, model engine simulator or high pressure air operation, model surface movement, hook-up and checkout can be accomplished with the data and control systems on the cart; however, a fiber optics network shall connect the cart to either data analysis room for customer checkout before moving the cart to the tunnel. Power shall be maintained on the cart during movement to the test section to maintain constant cooling to the analog equipment so as not to affect calibration coefficients or require a prolonged warm-up period.

### Criteria:

Cart Network Subsystems:

Standards: appropriate federal open systems standards that are applicable to networks - *TBD*

Reflective Memory Network Subsystem:

Transmission Media: *TBD*

Transfer Rates: *TBD*

Number of Nodes: *TBD*

Bus Architecture and Interface for Nodes: *TBD*

Memory per Node: *TBD*

LAN/Ethernet 802.3 Requirements: *TBD*

Number of Nodes: *TBD*

Transmission Media: *TBD*

Packet Transfer Rates: *TBD*

Other Network Requirements: *TBD*

Refer to each cart subsystem below for the appropriate criteria for that category of equipment.

### Test Static Data System

**Definition:** The test static data system acquires data from the test model, the model support systems, and other areas adjacent to the test section.

**Requirements:** Full software support is required for signal conditioning, system calibration, system diagnostics, conversion of data to engineering units and coefficients, and driving of real-time display systems for the technicians during model set-up and calibration. Appropriate data shall also pass to the on-cart model attitude control system for command and control of the model attitude, model engine simulators, and model surfaces. This system shall also synchronize and control the electronic pressure scanning system for acquiring up to 2000 ports of pressure data. Up to 256 channels of analog data shall be acquired and 24 channels of digital information. Digital information shall include binary, BCD, Datex code, resolver inputs, and special instruments requiring RS 232 or IEEE 488 protocol. When the cart is moved to the test section, a single X terminal shall be used to perform any required diagnostics through the data processor for final checkout. The cart shall then be connected by a fiber optics LAN to the central control room where command and control will be conducted during the test.

#### Criteria:

##### Data Acquisition Unit:

Size and Packaging: *TBD*  
Power Requirements: *TBD*  
Cooling Requirements: *TBD*

##### Active Filters:

Up to 4 programmable selections per channel - selections: *TBD*  
Filter Characteristics: 4 pole Butterworth or Bessel *TBD*

##### Signal Conditioning:

Channel Count Requirements: *TBD*  
Variable Transducer Supply Excitation Voltage Range: *TBD*  
Bridge Completion Characteristics: *TBD*  
Auto Zero Capability: *TBD*  
Modes supported: strain gage, thermocouple, RTD

##### Amplifier characteristics:

Amplifier Per Channel  
Input Impedance: greater than 10 megohm  
Common Mode rejection: 120 db minimum  
Gain Ranges: 12 minimum, covering 5 mv. up to 10 volt, FS

**Additional Features:**

Programmable Sampling Rate: *TBD*  
Automatic Calibration Capability: *TBD*  
Overall System Accuracy and Noise: *TBD*

**Computer Subsystem:**

Size and Packaging: *TBD*  
Power Requirements: *TBD*  
Cooling Requirements: *TBD*  
Standards: appropriate federal open systems standards *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*  
Bus Architecture: *TBD*

**Peripherals:**

Fixed Disk: Size, transfer rate, format *TBD*  
Removable Disk: Size, transfer rate, format *TBD*  
Optical Disk: Size, transfer rate, format *TBD*  
Archive Tape: Size, transfer rate, format *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF,  
meeting appropriate standards for networking, portability,  
and other features - *TBD*

Custom designed data acquisition, calibration, control, and real-time display software  
appropriate for meeting the acquisition and display requirements noted above - *TBD*

**Dynamic Pressure Data System**

**Definition:** The dynamic pressure data system will acquire data from the dynamic pressure instrumentation.

**Requirements:** Up to 80 channels of dynamic pressure data shall be acquired. It is anticipated that this system will have an analog to digital converter per channel with up to 10 megabytes of buffer ram per channel. Data shall be dumped to high speed 20 Gigabyte removable disks for archiving. The control processor shall support a graphical signal analysis package with the cart and shall be controlled from the central control room during tunnel testing. Each channel shall have programmable gain and filter setting with appropriate signal conditioning for the transducers. The system shall acquire data at up to 100 KHz per channel.

Criteria:

## Data Acquisition Unit:

Size and Packaging: **TBD**Power Requirements: **TBD**Cooling Requirements: **TBD**

## Active Filters:

Up to 4 programmable selections per channel selections: **TBD**Filter Characteristics: **TBD**

## Signal Conditioning:

Channel Count Requirements: **TBD**Variable Transducer Supply Excitation Voltage Range: **TBD**Bridge Completion Characteristics: **TBD**

Modes supported: strain gage, thermocouple, RTD

## Amplifier characteristics:

Amplifier Per Channel

Input Impedance: greater than 10 megohm

Common Mode rejection: 120 db minimum

Gain Ranges: 12 minimum, covering 5 mv. up to 10 volt, FS

Auto Zero Capability: **TBD**

## Additional Features

Programmable Sampling Rate: **TBD**Buffer Memory Size Per Channel: **TBD**Automatic Calibration Capability: **TBD**Overall System Accuracy and Noise: **TBD**

## Computer Subsystem:

Size and Packaging: **TBD**Power Requirements: **TBD**Cooling Requirements: **TBD**Standards: appropriate federal open systems standards **TBD**Clock Rate: **TBD**Processing Speed: **TBD**Memory Cycle time: **TBD**Memory Size: **TBD**Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. **TBD**Bus Architecture: **TBD**

**Peripherals:**

Fixed Disk: Size, transfer rate, format *TBD*  
Removable Disk: Size, transfer rate, format *TBD*  
Optical Disk: Size, transfer rate, format *TBD*  
Archive Tape: Size, transfer rate, format *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF,  
meeting appropriate standards for networking, portability,  
and other features *TBD*

Custom designed data acquisition, calibration, control, and real-time display software  
appropriate for meeting the acquisition and display requirements noted above *TBD*

**Hot Wire Anemometer Data System**

**Definition:** This system will record data from special signal conditioners utilizing constant temperature and constant current controllers for hot wire and hot film sensors. In addition, 24 channel of microphone data will also be provided. This system is used to measure hot wire and hot film anemometer instrumentation mounted directly on the model or in the tunnel air flow areas.

**Requirements:** One complete hot wire anemometer data system shall be provided for each cart. The system shall include the following components:

Sensors  
Surface Mounted Hot Film Anemometer CTA System  
Hot wire/Film Probe Anemometer CTA/CCA System  
Signal Conditioner AC/DC Splitter  
Static DAS (for reading DC component)  
Transient Data Recorder (TDR) DAS 100 Khz  
Transient Data Recorder (TDR) DAS 1.25 Mhz  
Anemometer DAS CPU  
Anemometer DAS Workstation

**Sensors -** Two types of sensors shall be provided: the constant temperature anemometer (CTA) and the constant current anemometer (CCA) hot wire probes and hot film. In addition, 24 microphones shall be employed to acquire acoustic data at rates up to 100 Khz.

Surface Mounted Hot Film Anemometer CTA System - The sensing units shall be powered and signal conditioned by a multi-channel anemometer system which provides computer control of calibration, gain, offset, and filtering. The output signal bandwidth shall be DC to 40 KHz and the output amplitude shall be 5 to 15 VDC and 1 to 750 Mv AC.

Signal Conditioner AC/DC Splitter - The analog output signals from the anemometer system shall be input to the signal conditioner units. These multi-channel units are required to buffer the incoming signal to two outputs. One output shall be AC coupled and one output shall be DC coupled. The AC coupled output amplifier shall block the DC signal component and provide selectable gain to drive the maximum of 10.24 volts into the TDR. The DC coupled output amplifier shall provide both gain and attenuation settings to drive or limit the maximum signal of 10.24 volts into the Static DAS.

Anemometer Static DAS - The Static DAS system shall consist of 80 channels of voltage inputs from the signal conditioner AC/DC splitter units. The Static DAS shall have a programmable low pass filter and auto-ranging gain capability. The selectable filters shall filter out the AC component of the anemometer signal. the channels, gains, and filter selection shall all be contained in a scan table that resides in the DAS unit. The scan rate shall also be programmable. The unit shall provide self calibration and correction capability.

Transient Data recorder (TDR) Das 100 KHz - The TDR shall provide high speed sampling and recording of multiple analog inputs at data rates up to 250 KHz. Sampled data shall be stored in 10 MB of on-board DRAM for each analog channel. The data shall be off loaded between runs through a high speed data bus and to disk. The unit shall feature a 16 bit analog to digital converter with input gain and low pass filtering. Unit calibration is required, using an external voltage calibration standard. Software and hardware features support system calibration. Several methods of triggering shall be available, including program control, external logic signal, and analog level detection on one channel. Twenty four additional channels shall be provided to acquire microphone data.

Transient Data Recorder (TDR) DAS 1.25 Mhz - The TDR shall provide high speed sampling and recording of multiple analog inputs at data rates up to 1.25 Mhz. Sampled data shall be stored in 10 MB of on-board DRAM for each analog channel. The data are required to be off loaded between runs through a high speed data bus and to disk. The unit shall feature a 16 bit analog to digital converter with input gain and low pass filtering control. Unit calibration shall be accomplished using an external voltage calibration standard. Software and hardware features support system calibration. Several methods of triggering shall be available, including program control, external logic signal, and analog level detection on one channel.

Anemometer DAS CPU - The Anemometer DAS CPU shall act as the host for controlling the data acquisition with the Anemometer Static DAS, the TDR 100 Khz and the TDR 1.25 Mhz. The calibration calculations and engineering units conversion shall also take place in the DAS CPU. The DAS CPU shall put the converted data out on the local area network as well as storing it on a local hard disk. A graphical user interface package shall be provided to control the acquisition process.

Anemometer DAS Workstation - The DAS workstation is required to act as the operator interface for the entire anemometer system. The local area network shall provide the link between the anemometer DAS CPU and the workstation. The programming and scan list creation, scan initialization, synchronization and semi-real time graphical display of the resultant data shall all be functions of the workstation. Software to run FFT's and perform other signal analysis on the data shall also be available. The operator interface software shall be a standard Windows compatible off the shelf package with enhancements.

#### Criteria:

##### Surface Mounted Hot Film Anemometer CTA System:

Size and Packaging: *TBD*

Power Requirements: *TBD*

Cooling Requirements: *TBD*

Channel Count Requirements: 64 channels per cart

Type Bridge: Non Linear, Constant Temperature type

Bridge Ratios: 1:10, 1:1

Sensor Resistance Range: 1:10 - 1-9.9 Ohms, 1:10 - 1.5-99 Ohms

Signal Conditioner Output Voltage: +/- 12V

Gain Accuracy: +/- 0.2%

Frequency Range: DC - 40 KHz

##### Hot Wire/Film Probe Anemometer CTA/CCA System:

Channel Count Requirements: 16 channels per cart

Type Bridge: Constant Current type

Signal Conditioner Output Voltage: +/- 12V

Accuracy: +/- 0.5%

Frequency Range: DC - 500 KHz

**Signal Conditioner AC/DC Splitter:**

Channel Count Requirements: 80 channels per cart

Selectable gain steps: *TBD*

Frequency Response: DC - 500 KHz

Two Buffered Outputs per Input:

Output 1: DC Coupled, +/- 12V

Output 2: AC Coupled, +/- 12V

Linearity: 0.005% of full scale

**Static DAS:**

Active Filters:

Up to four programmable selections per channel; 1 Hz, 10 Hz, 100 Hz, 1000 Hz.

Filter Characteristics:

4 pole Butterworth or Bessel - *TBD*

Amplifier Characteristics:

Amplifier Per Channel

Input Impedance: Greater than 10 Megaohm

CMR: 120 dB minimum

Gain Ranges: 12 minimum, 5 mV up to 10.24V FS

Additional Features:

Programmable Sample Rate: *TBD*

Automatic Calibration Capability: *TBD*

Overall System and Noise: *TBD*

**Transient Data Recorder DAS 100 KHz:**

Sample Rate: Programmable, 100 KHz minimum

Amplifier Characteristics:

Programmable Gain: *TBD*

Programmable Filter: *TBD*

A/D Resolution: 14 Bits

Buffer Memory: 10 MB

Trigger Modes: Programmable, external, level detection

Accuracy: *TBD*

Phase Coherency: *TBD*

Calibration: *TBD*

Interface: High Speed DMA style, 2 MB/sec transfer rate

**Transient Data Recorder DAS 1.25 MHz:**

Sample Rate: Programmable, 1.25 MHz minimum

**Amplifier Characteristics:**

Programmable Gain: *TBD*

Programmable Filter: *TBD*

A/D Resolution: 12 Bits

Buffer Memory: 10 MB

Trigger Modes: Programmable, external, level detection

Accuracy: *TBD*

Phase Coherency: *TBD*

Calibration: *TBD*

Interface: High Speed DMA style, 2 MB/sec transfer rate

**Anemometer DAS CPU:**

Standards: Appropriate federal open systems standards *TBD*

Clock Rate: *TBD*

Processing Speed: *TBD*

Memory Cycle Time: *TBD*

Memory Size: *TBD*

Interfaces Supported: IEEE-488, SCSI, RS 232, FDDI, etc. *TBD*

Bus Architecture: *TBD*

Network Interfaces and Packet Transfer Rates: *TBD*

**Anemometer DAS Workstation:**

Processor Type (RISC, CISC): *TBD*

Clock Speed: *TBD*

Memory: *TBD*

Disk Capacity: *TBD*

Data Interchange/Software Distribution Media: *TBD*

Graphics Capability: *TBD*

Archive Capability/Media: *TBD*

Expansion Slots: (S-Bus, VME, etc.) *TBD*

Cache Size: *TBD*

Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF, meeting appropriate standards for networking, portability, and other features **TBD**

Custom designed data acquisition, control, and real-time display software appropriate for meeting the acquisition and display requirements noted above **TBD**

Data Analysis Software Tools - Software for signal processing, visualization, data reduction, database management, and other features typically required for data analysis. Final Requirements **TBD**

**Acoustic Data System**

**Definition:** A modular high speed dynamic data system provides a system for acquiring acoustic data.

**Requirements:** The system shall be made up of modules containing about 16 channels of A/D, memory, filters, a CPU and a disk drive. The total system shall be made up of enough modules to acquire 256 channels of data. Although most of the A/D channels will be capable of data sampling up to 50,000 samples/sec, one module (16 channels) shall be capable of acquiring data at 250,000 samples/sec. The system modules can be assembled to meet specific test objectives, such as a low speed test where many channels would be required, or a high speed test with fewer sensors but high data sampling rate requirements. In conjunction with the acoustic data acquisition system, a collection of microphones, pre amplification equipment, cables, and calibration equipment shall be provided

**Criteria:**

Microphones: **TBD**

**Signal Conditioning:**

Number of Channels: 256

Pre-amp Gain Steps: **TBD**

Calibration Capability: **TBD**

Frequency Range: **TBD**

Output Voltage: **TBD**

Excitation Supply: **TBD**

Bridge Completion: **TBD**

**A/D Modules:**

Number of Channels: 256  
Programmable Gain Steps: *TBD*  
Programmable Filter Steps: *TBD*  
Sample Rate (All Channels Scanned): 50 KHz  
Sample Rate (16 Channels): 250,000 KHz  
Memory: *TBD*  
Interface: High Speed DMA type, 2 MB/sec transfer rate

**Acoustic DAS Computer subsystem:**

Standards: Appropriate federal open systems standards *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle Time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE-488, SCSI, RS 232, FDDI, etc. *TBD*  
Bus Architecture: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*  
Disk Capacity: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF, meeting appropriate standards for networking, portability, and other features *TBD*

Custom designed data acquisition, control, and real-time display software appropriate for meeting the acquisition and display requirements noted above *TBD*

Data Analysis Software Tools - Software for signal processing, visualization, data reduction, database management, and other features typically required for data analysis.  
Final Requirements *TBD*

**1.4.5.4 Instrumentation**

**Definition:** Overall instrumentation system of the Low Speed Wind Tunnel (LSWT) Complex includes four major instrumentation components and an additional one that integrates the entire instruments and their associated components. These five components are: Test Instrumentation, Calibration Instrumentation, Acoustics Instrumentation, Process Instrumentation, and Hardware Integration.

Test instrumentation is a stand-alone instrument system that is intended to acquire fluid dynamic parameters required of wind tunnel experiments of a given model in the test section of the tunnel. The test instrumentation system is an integral part of the four test section carts, and links to various computers and workstations of the tunnel complex through a high speed control and data bus of the tunnel data acquisition and control system. These carts are the test section internal components, consisting of movable walls, model support systems, and model support

structures. The test section cart is placed and transported in a movable plenum cart which translates in and out of the tunnel circuit on a rail.

Calibration instrumentation systems are intended for tunnel calibrations as well as for tunnel shakedown operations. Information obtained by the calibration instrument systems are made available to the computers and workstations of the LSWT Complex through the high speed control and data bus. Acoustic instrumentation systems are used to obtain acoustic properties of open jet configurations, such as acoustic rake survey data and effectiveness of the acoustic enclosure/treatment. Process instrumentation systems monitor various tunnel parameters, with specific emphasis on those related to the flow quality and tunnel safety, which are fed back to the tunnel control devices.

Hardware integration of the above four components of instrumentation system are required to interconnect the various instruments and systems to function in a manner prescribed by the experimental and safety requirements.

#### **Requirements:**

**Test Instrumentation:** There shall be four test instrumentation systems for the four test section carts. These four carts shall be fully assembled with the test instrumentation system and operate independently. The test instrumentation systems shall measure aerodynamic and related parameters including: force, skin-friction, static and dynamic pressure, acceleration, displacement, rotation, acoustic, and temperature. In addition, the test instrumentation systems shall have self-contained optical capabilities of making measurements of model deformation, angle-of-attack, flow visualization, and high speed video surveillance.

**Calibration Instrumentation:** The calibration instrumentation systems shall provide pressure data for center-line, rotary rakes, circuit, fluctuating wall, and compressor. The calibration instrumentation shall also provide data on: vibration, rotary rake total temperatures, boundary layer rakes, and strain of the tunnel structures.

**Acoustic Instrumentation:** The baseline requirement for acoustic measurements shall be for obtaining acoustic information about open jet traverse and test section. In addition, the system shall provide acoustic data for tunnel baseline calibration.

**Process Instrumentation:** The instrumentation systems for tunnel processing shall provide data for Mach numbers, pressures and temperatures for the cooler system, a series of pressures, temperatures, vibrations, positions, and angles for the tunnel compressor. Process instrumentation systems shall also furnish information for the following parameters: test section wall positions, tunnel circuit dew points, motor power/voltage, water flow, high pressure compressor, dryer, vacuum pump, vacuum storage tank, cool tower, heat exchanger, choke finger positions, and nozzle jack positions.

**Hardware Integration:** The test section cart includes the test section floor model support systems and attached instrument housing. The pressure connections for all test instrumentation shall penetrate the instrument housing wall that will make up part of the pressure vessel when

installed in the tunnel. Wires attached to instrumentation inside the model or sting shall exit through the test section floor and then shall exit the tunnel through the instrument housing pressure wall. A production oriented facility requires the complete test section (not just the floor) to be made available in the model preparation bays for set-up, alignment, and equipment warm-up and stabilization. Permanent connections mounted on one wall of the main test section plenum near the area that the test cart instrument housing would reside shall be provided. Optical instruments shall be patched into the instrument housing after the cart assembly is in place and ready for a test run. The process instrumentation wiring shall be designed to provide flexibility during normal testing and also provide tunnel calibration facilities when used in conjunction with one of the test section carts. One ESP system (two counting the cart system) shall make up the majority of pressure measurements. The Mach Number System shall include two completely independent measuring systems for redundancy. The three uniform temperature references (UTR) shall be provided and have the ability to provide cold junction compensation for any type of thermocouple and can also be used for any analog signal input to the data systems. The strain gage junction boxes shall provide power, sense, re-calibration, and signal conditioning for discrete bridge type instrumentation. These junction boxes can also be used to input other analog signals into the data system.

### **Criteria:**

#### **Test Instrumentation:**

##### **Pressure Measurements**

Test Section (Static) - 400 channels	<b><i>TBD</i></b>
Model Module (Static) - 2000 channels	<b><i>TBD</i></b>
Dynamic Pressures - 80 channels	<b><i>TBD</i></b>

##### **Temperature Measurements**

T/C and RTD - 24 channels	<b><i>TBD</i></b>
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##### **Angle Of Attack**

Inertial System - 3 channels	<b><i>TBD</i></b>
Optical System	<b><i>TBD</i></b>

##### **Vibration - 4 channels**

***TBD***

##### **Component Position System**

***TBD***

##### **High Speed Video System**

Surveillance and Safety - 6 channels	<b><i>TBD</i></b>
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Structural/Model Vibration - 6 channels	<b><i>TBD</i></b>
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##### **Model Deformation Systems**

***TBD***

##### **Vapor Screen**

***TBD***

##### **Skin Friction Balance System**

***TBD***

##### **Anemometer System**

***TBD***

##### **Flow Visualization**

Laser Light Sheet	<b><i>TBD</i></b>
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Tufts and Oil Flow	<b><i>TBD</i></b>
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Calibration Instrumentation:

Center Line Probes	
Static Pressures - 300 channels	<i>TBD</i>
Acceleration - 2 channels	<i>TBD</i>
Rotary Rake	
Flow Angle	<i>TBD</i>
Temperatures (Ref. to Test Instrumentation)	
Pressures (Ref. to Test Instrumentation)	
Turbulence (Ref. to Test Instrumentation)	
Circuit Static Pressures (Ref. to Test Instrumentation)	
Fluctuating Pressures - 10 channels	<i>TBD</i>

Acoustic Instrumentation:

0.25 inch Microphone Systems - 24 channels	<i>TBD</i>
0.5 inch Microphone Systems - 24 channels	<i>TBD</i>
5 Hz to 40 KHz bandwidth	
96 dB Dynamic Range	
Max. Sound Pressure Level :164 dBs	

Process Instrumentation:*TBD*

Mach Number Systems  
 Cooler (Pressures and Temperatures)  
 Compressor System  
     Inlet and Outlet Pressures  
     Inlet and Outlet Temperatures  
     Oil Pressures and Temperatures  
     Vibration  
     Eddy Current Probes  
     RPM and Position  
     Angles (Roll, Pitch, Turntable)  
 Test Section Wall Position  
 Dew Points  
 Motor Power/Voltage  
 Water Flow  
 Air Nozzle Instrumentation  
 High Pressure Compressor System  
 Dryer  
 High Pressure Air Storage and Heater  
 Vacuum Pump System  
 Cool Tower  
 Heat Exchanger  
 Valve Positions

**Hardware Integration:**

Test Cart Wiring	<i>TBD</i>
Optical System	<i>TBD</i>
Process Instrumentation Wiring	<i>TBD</i>

**1.4.5.5 Predictive Maintenance System**

**Definition:** The predictive maintenance system includes all the electrical/electronic components, cabling, and software required to monitor the health of the LSWT, provide indications for nonscheduled maintenance, and predict normal maintenance schedules for components/subsystems. This WBS does not include sensors.

**Requirements:** The predictive maintenance system must acquire data at a rate and accuracy to ensure readiness of LSWT to operate. The system will utilize redundant sensors where necessary to minimize nuisance trips due to errors in individual sensors and system noise. Advanced on-line AI techniques are needed to minimize maintenance requirements and rapidly identify and isolate problems in specific components when operational status is threatened. Communication is required between this system and the control systems for the tunnels and auxiliary systems.

**Criteria:**

• Standards:	<i>TBD - Design</i>
• System Availability	<i>TBD</i>
• Data Sample Rate	<i>TBD</i>
• Data Accuracy	<i>TBD</i>
• Solution Time for Failure Identification	<i>TBD</i>
• Communication Rate for Control Systems	<i>TBD</i>

**1.4.6 Activation****1.4.6.1 Integrated System Checkout**

**Definition:** The LSWT checkout is initiated when all of the system-level component checks have been completed and any significant deficiencies, identified in the process, have been corrected. An Integrated Systems Review (ISR) will be conducted to validate readiness prior to initiation of the integrated system testing of the LSWT facility.

**Requirements:** The integrated system testing matrix shall include operation of the facility to the boundaries of the performance envelope to determine/document the safe limits of the facility operation. A tiered approach to integration of the system testing requirements shall be utilized

to ensure equipment/personnel safety during checkout. A comprehensive checkout plan which describes the required elements of LSWT integrated system testing shall be prepared as part of this work element.

Criteria: *TBD*

#### **1.4.6.2 Tunnel Calibration**

Definition: Validation/calibration of the LSWT facility includes the activities associated with the measurement of the test section flow parameters over the range of facility test conditions to (1) validate compliance to requirements (flow quality, performance, etc.) and (2) provide a basis for the development of the test section calibration.

Requirements: This work element shall include all labor, materials and utilities required to conduct the LSWT validation/calibration from planning through calibration. An Operational Readiness Review (ORR) shall be conducted prior to the initiation of validation/calibration testing in the facility. The ORR shall provide a comprehensive assessment of the facility, equipment, procedures, staffing and overall readiness for initiation of validation/calibration testing.

Criteria: *TBD*

#### **1.4.6.3 Provisioning**

Definition: This work element provides all of the equipment required to maintain the productivity of the LSWT facility during normal operations. The equipment will include all of the routinely replaced parts which can fail and must be available for rapid replacement.

Requirements: *TBD*

Criteria: *TBD*

**1.5 TRANSONIC SPEED WIND TUNNEL (TSWT)****Definition:**

The Transonic Speed Wind Tunnel (TSWT) will have the following major features: a closed circuit, pressurized air, wind tunnel; a removable plenum and test section; a plenum and test section pressure/vacuum isolation system; high productivity; and superior flow and data quality.

**Requirements:** Specific TSWT requirements are given in Tables 1.5.a through h

**Table 1.5.a TSWT Performance Requirements**

<b>Performance Requirements</b>	<b>See Figure 1.4.a</b>
Mach Number Range	0.05 to 1.5
Total Pressure Range	0.07 to 5 atm
Test Section Shape	Rectangular, No Fillets
Test Section Size	11 x 15.5 ft - 170.5 ft <sup>2</sup>
Test Section Length	<i>TBD</i>
Maximum Temperature °F	Ambient + 30°F
Test gas	Air
Drive Power Design Point	M = 1.0, Pt = 5 atm, Tt = 100°F, Model Drag of 11,000 lbs

**Table 1.5.b TSWT Acoustics Requirements**

<b>Acoustics Requirements</b>	
In-Flow and Out-of-Flow Noise Specifications	See Figure 1.5.b
Anechoic Chamber	No
Acoustic Frequency Range	100-20,000 Hz
Total Pressure During Acoustic Testing	0.07 to 1 atmosphere
Test Section Type	Closed Jet

**Table 1.5.c TSWT Productivity Requirements**

<b>Productivity</b>	
Average Productivity Rate Using Benchmark Test Program (See Appendix A.4)	8 Polars/Occupancy Hour
Removable Plenum and Test Section Carts	Yes
Cart Quantities and Types	4 (2 Slotted Rear Sting, 1 Slotted Floor Mount, 1 Acoustic Strut Support)
Tunnel Pressure Isolation System	Yes

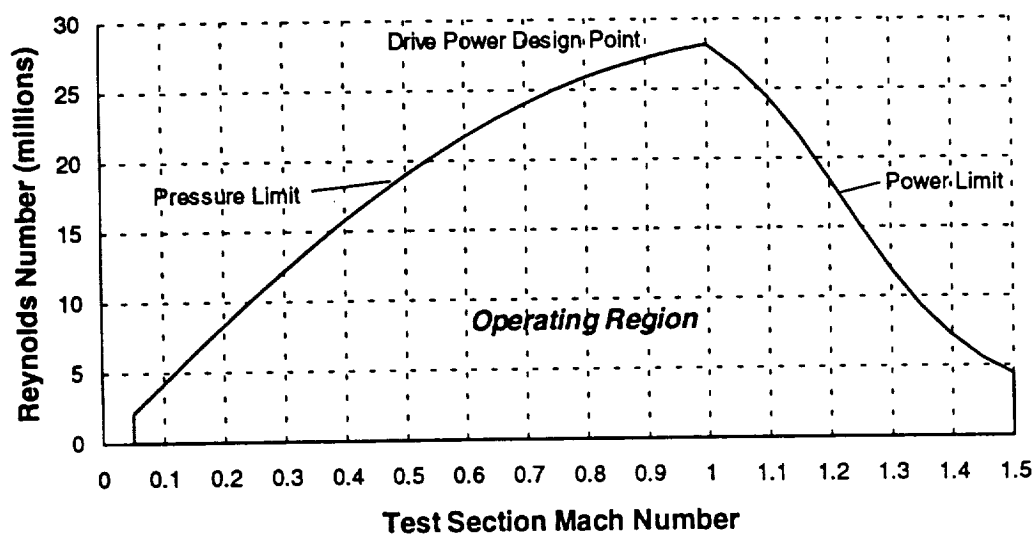


Figure 1.5.a TSWT Performance Envelope  
(Full Span Model, Reference Length -  $c_{bar} = 1.31$  feet)

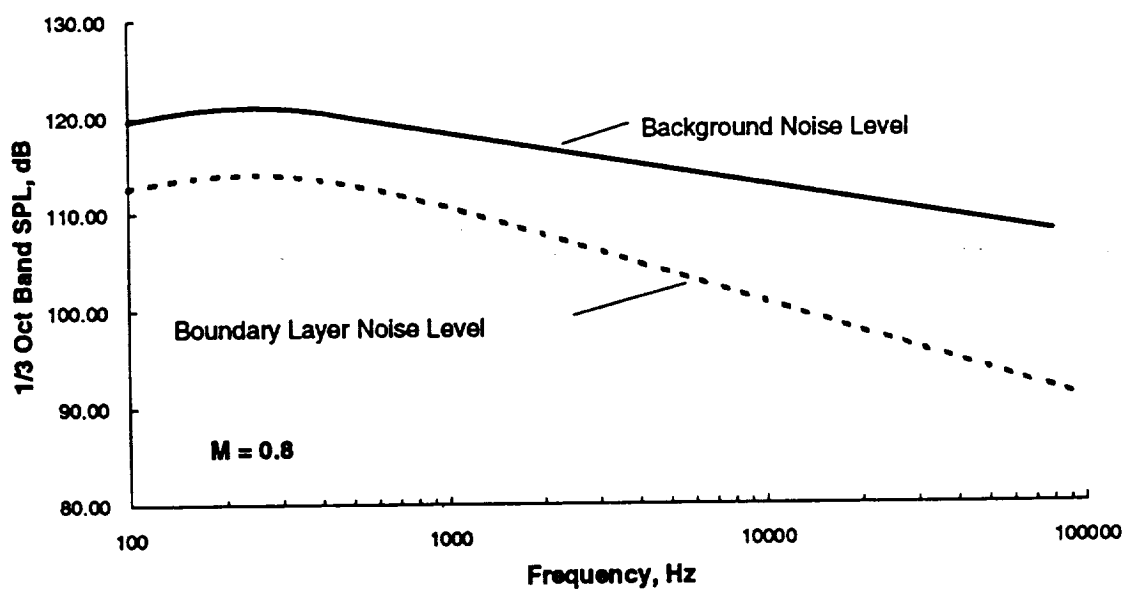


Figure 1.5.b TSWT Background Noise

Table 1.5.d TSWT Data Quality Requirements

Data Quality Requirements	
Flow Quality	Closed Jet
Test Volume for Flow Quality Requirements	<i>TBD</i>
Total Temperature Distribution	$\pm 1.0^{\circ}\text{F}$ , Within Test Volume
Turbulence, %	0.04 Longitudinal, 0.08 Vertical, 0.08 Lateral, Within Test Volume
Noise, RMS	95.0 dB, Within Test Volume
Stream Angle Deviation	$< \pm 0.1^{\circ}$ , Within Test Volume
Stream Angle Gradient	$0.01^{\circ}/\text{ft}$ , Along Any Line Within Test Volume
Mach Number Distribution	$\pm 0.001$ Subsonic, Along Tunnel Centerline $\pm 0.01$ Supersonic, Along Tunnel Centerline $\pm 0.001$ In a Cross Section At Center Of Model Rotation $\pm 0.0005/\text{ft}$ Along Centerline Over Length Of Test Volume
Tunnel Stability: Total Pressure Total Temperature Mach Number	$\pm 1$ psf Over a 10 sec Period $\pm 0.5^{\circ}\text{F}$ Over a 10 sec Period $\pm 0.0005$ Over a 10 sec Period

Table 1.5.e TSWT Data Acquisition System Requirements

Data Acquisition System Requirements	
Overall System Accuracy (for any signal)	<i>TBD</i>
Overall System Response or Settling Time (for any parameter)	<i>TBD</i>

Table 1.5.f TSWT Model Propulsion Requirements

Model Propulsion Requirements	Turbine Power Simulator	High Bypass (Simultaneous)	Fighter
Mass Flow Rate, lbs/sec	35	30	100
Temperature At Model, $^{\circ}\text{F}$	400	200	200
Pressure At Model, psia	3000	300	2500
Run Distribution	Continuous	Continuous	15 Minutes Out Of Every 30 Minutes

Table 1.5.g TSWT Closed Jet Model Loads

Closed Jet Model Loads			
	Rear Strut Mount Full Span No Roll	Rear Strut Mount Full Span With Roll	Floor Mount Semispan
Lift Force, lbs	±53,520	±26,850	±53,700
Drag Force, lbs	±10,650	±5,400	±10,750
Side Force, lbs	±5,400	±2,250	±10,800
Pitching Moment, ft-lbs	±41,550	±14,850	±59,000
Rolling Moment, ft-lbs	±18,550	±2,250	±221,500
Yawing Moment, ft-lbs	±6,200	±11,000	±88,600
Note: Loads are for unpowered models referenced to 1/4 mean aerodynamic cord at the plane of symmetry (5 atmospheres)			

Table 1.5.h TSWT Closed Jet Model Positioning Requirements

Closed Jet Model Positioning Requirements		
	Rear Strut Mount	Floor Mount
Pitch Angle Range, degrees	<i>TBD</i>	<i>TBD</i>
Pitch Speed Range, degrees/sec	<i>TBD</i>	<i>TBD</i>
Pitch Positioning Accuracy, degrees	<i>TBD</i>	<i>TBD</i>
Yaw Angle Range, degrees	None	<i>TBD</i>
Yaw Speed Range, degrees/sec	None	<i>TBD</i>
Yaw Positioning Accuracy, degrees	None	<i>TBD</i>
Roll Angle Range, degrees	<i>TBD</i>	None
Roll Speed Range, degrees/sec	<i>TBD</i>	None
Roll Positioning Accuracy, degrees	<i>TBD</i>	<i>TBD</i>

### 1.5.1 Pressure Vessel System

**Definition:** The pressure vessel system includes all components of the outer pressure containing shell of the TSWT, with the exception of the following:

- The TSWT Rolling Plenum Shell- included in Section 1.5.2.
- The TSWT Compressor Section Shell - included in Section 1.5.4.

The pressure vessel system also includes the following: foundation, structural supports, pressure shell with shell penetrations to the first flange, external stiffening rings, and tunnel isolation valves.

### 1.5.1.1 Foundation

**Definition:** The foundation for the tunnel pressure vessel system is site dependent. It is a reinforced concrete structure, supporting the weight of the pressure shell (including the weight of water during hydrostatic testing), the tunnel internal structures, and the tunnel enclosure. The foundation consists of a reinforced concrete basemat with embedded plates and bolts to facilitate the attachment of tunnel enclosure steel and pressure shell supports and anchors. It is a stepped design, varying from grade level in the building and model preparation areas to well below grade underneath the tunnel.

**Requirements:** The TSWT pressure shell shall be supported on a common foundation. The intent is to keep a constant elevation for the cart rails from the preparation hall into the tunnel. The tunnel shell anchor point and anchor/foundation stiffness requirements are *TBD*.

**Criteria:**

**Table 1.5.1.1.a TSWT Foundation Criteria**

Parameter	Requirement
Design Standards	<i>TBD</i> , Site Dependent
Allowable Soil/Pile Capacity	
Seismic/Earthquake Requirements	
Foundation Loads	<i>TBD</i> , Design Process
Empty Pressure Shell Weight	
Weight of Test Section Internals	
Weight of Water During Hydro Test	
Dynamic Loads	
Tunnel Operational Loads	<i>TBD</i> , Ref.: Aerolines Study

### 1.5.1.2 Structural Supports

**Definition:** The structural supports are vertical columns and cross braces which support and stabilize the tunnel shell and internals. Connections are provided to permit longitudinal and lateral movement of the tunnel with respect to the single fixed anchor point.

**Requirements:** The structural supports shall anchor the tunnel shell to the foundation, provide vertical support for the tunnel, and allow longitudinal and lateral movement of the shell relative to the tunnel anchor point.

**Criteria:**

Table 1.5.1.2.a TSWT Structural Support Criteria

Parameter	Requirement
Design Standards	AISC Steel Construction Code
Allowable Tunnel Deflections	<i>TBD</i> , Ref. Aerolines and Plenum/Cart Study
Spacing and Centerline Height of Tunnel	<i>TBD</i> , Design Process
Design Loads	<i>TBD</i> , Design Process
Empty Pressure Shell Weight	
Weight of Test Sect. Internals	
Weight of Water, Hydro Test	
Dynamic Loads	
Anchor Point Location and Stiffness	<i>TBD</i> , Ref. Aerolines Study

### 1.5.1.3 Pressure Shell

**Definition:** The pressure shell is the outer structure in the wind tunnel, which contains the pressure. It is also the flow boundary around the tunnel circuit, except through the settling chamber and high speed diffuser regions. The pressure shell has the following sub-elements: Test Section/Plenum Outer Shell, Downstream Isolation Shell, Test Section Diffuser Shell, Corner #1, Cross Leg #1, Corner #2, Tail Section, Compressor Diffuser Shell, Corner #3, Crossleg #2, Corner #4, Settling Chamber Shell, Upstream Isolation Shell, Fixed Plenum Shell.

The following tunnel sections are also pressure vessels, but have been included in other work packages for convenience:

- The Rolling Plenum - included in WBS 1.5.2.
- The Compressor Section Shell - included in WBS 1.5.4.

This work package also includes external stiffening rings, shell penetrations and internal supports for components located within the shell, as well as all activities related to obtaining an ASME Section VIII, Code stamp.

**Requirements:** The pressure shell is constructed of curved plates, ring girders, stringers, flanges, bulkheads, gussets, and stiffeners. The pressure shell will interface with the test section plenum and compressor sections. Penetrations are required for instrumentation, tunnel access, pressurization/evacuation, drive shaft, manways, cooling water, and lubrication. The tunnel cross section is circular with square corner and conical sections.

**Criteria:**

Table 1.5.1.3.a TSWT Pressure Shell Criteria

Parameter	Requirement
Standards	The pressure shell is designed, constructed, inspected , tested, and U stamped in accordance with the ASME Code Sect. VIII.
Operating Pressure Range:	14 psig external to 66 psig internal pressure
Design Pressure Range	15psig external to 70 psig internal pressure
Design Temperature	0 to 140 ° F
Design Life	Definition and operational cycles <i>TBD</i>
Overall Dimensions	<i>TBD</i> , Ref.: Aeroline Study
Material	ASME Code Approved
Location, Size and Loads of Penetrations	<i>TBD</i> , Design Process
Coatings	Interior and exterior surfaces shall be painted

#### 1.5.1.4 Isolation Valves

**Definition:** The upstream and downstream isolation valves are two large gate valves, one upstream and one downstream of the test section, which can be rapidly actuated to isolate the high pressure air from the test section area. The test section area can then be rapidly vented, so models can be quickly modified in place or changed using the movable plenum/test section cart concept. The isolation valves include the following sub-elements: Housing/Flange, Gate Structure, Gate Guide Mechanism, Gate Actuation System, Sealing System, Power System, Controls System.

**Requirements:** Two sliding gate valves shall be provided, one upstream and one downstream of the test section, each consisting of flat or semi-elliptical heads with full edge flanges. The valves may be designed horizontally or vertically. Each valve shall be powered by a quick acting drive system. The gate of the valve shall slide in a guided rail system. The valves shall be stored in a well beneath or to the side of the tunnel flow stream completely enclosed in the pressure plenum. Seals are required to prevent leakage past the gates in the open and closed positions under a wide range of operating conditions.

**Criteria:**

Table 1.5.1.4.a TSWT Isolation Valve Criteria

Parameter	Requirement
Standards	The isolation valves are designed, constructed, inspected, tested, and U-stamped in accordance with the ASME Code Section VIII.
Operating Pressure Range	14 psig external to 66 psig internal pressure
Design Pressure Range	15 psig external to 70 psig internal pressure
Design Temperature	0 to 140 ° F
Overall Dimensions	<i>TBD</i> , Ref.: Aeroline Study
Size	<i>TBD</i> ,
Material	ASME Code Approved
Seals	Active trapped continuous pressure seals on mating surfaces of pressure shell bulkhead in open and closed positions. Leakage Rate (open): <i>TBD</i> Leakage Rate (closed): <i>TBD</i>
Opening/Closing Speeds	<i>TBD</i> , Ref.: Productivity Study
Allowable Steps/Gaps In Flow Surface	<i>TBD</i> , Ref.: Aeroline Study
Automated Controls	<i>TBD</i>

## 1.5.2 Plenum / Test Section System

### 1.5.2.1 Rolling Plenum

**Definition:** The rolling plenum is a removable section of the tunnel circuit, which houses the test section. It can be disconnected from the stationary pressure shell and rolled out of the circuit for the purpose of making rapid model changes. The rolling plenum pressure shell includes penetrations for personnel access and data/instrumentation connections. The rolling plenum includes the following sub-elements: Rolling Plenum Shell, Plenum Internal Structure, Plenum External Structure, Plenum Drive System, Plenum Alignment and Latching System, Plenum Sealing System, Plenum Control System.

**Requirements:** Achievement of the high productivity requirements for the facility is partially dependent on the successful and reliable performance of the tunnel carting system. The rolling plenum is a critical component in the tunnel carting system. The rolling plenum can either be positioned in front of one of various cart bays for loading and unloading of the test section / model support system assembly or be moved into the tunnel circuit for operational testing. Optimization of the process for making in-place model changes and of process for interchanging models in the tunnel circuit is a significant factor in being able to meet the stringent productivity requirements. The system productivity requirements are presented in Section 1.5.0 for the selected Benchmark Test Program outlined in Appendix B.

Special, quick exchange type penetrations ports shall be used to pass electrical, data acquisition, and instrumentation leads through the pressure shell. Very precise alignment of the flow surfaces is required in order to maintain the flow quality requirements. An automatic latching and alignment mechanism shall be used to quickly and positively align and lock the rolling plenum in place. A sealing system shall be used to minimize leakage through the pressure vessel.

Criteria:

**Table 1.5.2.1.a TSWT Rolling Plenum Criteria**

Parameter	Requirement
Standards	The rolling plenum is designed, constructed, inspected, tested, and U-stamped in accordance with the ASME Code Section VIII.
Operating Pressure Range	14 psig external to 66 psig internal pressure
Design Pressure Range	15 psig external to 70 psig internal pressure
Design Temperature	0 to 140 ° F
Design Life	<i>TBD</i> , Ref.: Aeroline Study
Internal Loads	<i>TBD</i> , Ref.: Aeroline Study
Shell Materials	ASME Code Approved
Installation/Removal Speed	<i>TBD</i> , Ref.: Productivity Study
Alignment Requirements During Installation	<i>TBD</i> , Ref.: Aeroline Study
Allowable Steps/Gaps At Mating Flanges	<i>TBD</i> , Ref.: Aeroline Study
Overall Stiffness Requirements For External Balance	<i>TBD</i> , Ref.: Plenum/Cart Study
Reliability	<i>TBD</i> , Ref.: Productivity Study

### 1.5.2.2 Sting Mount Test Section

**Definition:** The sting mount test section is a four sided welded and machined steel structure with adjustable sidewalls, which houses the Rear Sting Model Support System, Section 1.5.2.4. All four walls of the test section have slots. The sting mount test section includes the following sub-elements: Outer Structural Frame, Walls/Actuators, Drive System, Alignment & Latching System, Sealing System, Controls System.

**Requirements:** Two sting mount test sections are required for the TSWT. The sting mount test sections are two of four interchangeable test sections (one of three interchangeable test section types). The sting mount test sections and the sting mount model support systems are installed in the rolling plenum as an integral unit. Optimization of the process for interchanging test sections and models in the tunnel circuit is a significant factor in being able to meet the stringent productivity requirements. The system productivity requirements are presented in Section 1.5.0 for the selected Benchmark Test Program outlined in Appendix B.

Very accurate fabrication and machining tolerances and very precise alignment of the flow surfaces is required in order to maintain the flow quality requirements in the test section. An automatic latching and alignment mechanism shall be used to quickly and positively align and lock the sting mount test section in place. A sealing system shall be used to minimize leakage into the test section from the plenum area. Observation windows shall be provided in the test section, as specified below. Model access for efficiently making minor model changes in the tunnel is a critical productivity item.

#### Criteria:

**Table 1.5.2.2.a TSWT Sting Mount Test Section Criteria**

Parameter	Requirement
Standards	<i>TBD</i>
Inside Dimensions	See Table 1.5.a
Test Section Fillets	See Table 1.5.a
Test Section Area	See Table 1.5.a
Flow Quality In Test Section	See Table 1.5.d
Installation/Removal Speed	<i>TBD</i> , Ref.: Productivity Study
Design Loads	<i>TBD</i> , Ref.: Aeroline Study
Alignment Requirements During Installation	<i>TBD</i> , Ref.: Aeroline Study
Overall Stiffness Requirements	<i>TBD</i> , Ref.: Plenum/Cart Study
Observation Windows Size, Number, & Spacing	<i>TBD</i>

#### **1.5.2.3 Floor Mount Test Sections**

**Definition:** The floor mount cart is a four sided, welded and machined steel structure with adjustable sidewalls which houses the external balance and floor mount model support assembly, Section 1.5.2.5. All walls of the test section have slots. The floor mount test sections include the following sub-elements: Outer Structural Frame, Walls/Actuators, Drive System, Alignment & Latching System, Sealing System, Control System.

**Requirements:** The floor mount test section is a critical component in the tunnel carting system. The floor mount test section is one of three interchangeable test section types. The floor mount test section and the floor mount model support system/ external balance are installed in the rolling plenum as an integral unit. Optimization of the process for interchanging test sections and models in the tunnel circuit is a significant factor in being able to meet the stringent productivity requirements. The system productivity requirements are presented in Section 1.4.0 for the selected Benchmark Test Program outlined in Appendix B.

Very accurate fabrication and machining tolerances and very precise alignment of the flow surfaces are required in order to maintain the flow quality requirements in the test section. An automatic latching and alignment mechanism shall be used to quickly and positively align and lock the sting mount test section in place. A sealing system shall be used to minimize leakage

into the test section from the plenum area. Observation windows shall be provided in the test section, as specified below.

**Criteria:**

**Table 1.5.2.3.a LSWT Floor Mount Test Section Criteria**

Parameter	Requirement
Standards	<i>TBD</i>
Inside Dimensions	See Table 1.5.a
Test Section Fillets	See Table 1.5.a
Test Section Area	See Table 1.5.a
Flow Quality In Test Section	See Table 1.5.d
Installation/Removal Speed	<i>TBD</i> , Ref.: Productivity Study
Design Loads	<i>TBD</i> , Ref.: Aeroline Study
Alignment Requirements During Installation	<i>TBD</i> , Ref.: Aeroline Study
Overall Stiffness Requirements	<i>TBD</i> , Ref.: Plenum/Cart Study
Observation Windows Size, Number, & Spacing	<i>TBD</i>

**1.5.2.4 Rear Sting Model Support System**

**Definition:** The rear sting model support system is the mechanical structural system that accurately positions sting mounted models in the test section under high aerodynamic loading conditions. The rear sting model support system includes a pitch assembly and a roll coupling, which attaches to the strut by a mechanical interface. The rear sting model support system includes the following sub-elements: Vertical Strut, Pitch Mechanism, Vertical Translation Mechanism, Roll Mechanism, Walls/Actuators, Drive System, Alignment & Latching Mechanism, Sealing System, Auxiliary Systems, Control & Data Acquisition System.....

**Requirements:** Two rear sting model support systems are required for the TSWT. Sting supported models using internal balances shall be supported from a pitch strut located in the downstream portion of the test section. The rear sting model support systems shall be moved from the tunnel, when not in use. The pitch mechanisms must be capable of maintaining a constant model height throughout the pitch range with various sting lengths (i.e. variable pitch point), and be capable of vertical traverse motion at any constant angle of pitch within the capable range. The systems must be designed for specified model loads with a cross section designed for minimal blockage effects.

Provisions for simultaneous pitch and roll are required. The strut cross sections shall be contoured to minimize aerodynamic losses and interference with test section flow qualities. Provisions must be made for instrumentation, air and power ducting in the vertical strut and model support sting.

Revision CCriteria:

- |                                     |                                   |
|-------------------------------------|-----------------------------------|
| • Standards:                        | Models Design Criteria            |
| • Model Loads                       | See Section 1.5.g                 |
| • Positioning Requirements:         | See Section 1.5.h                 |
| • Deflection or Stiffness Criteria: | <b>TBD</b>                        |
| • Blockage Criteria:                | <b>TBD</b> , Ref.: Aeroline Study |

**1.5.2.5 Floor Mount Model Support Systems**

**Definition:** The floor mount model support system is a second mechanical structural system that accurately positions floor mounted models in the test section under high aerodynamic loading conditions. The floor mount model support system includes a pitch mechanism and a yaw turntable. An external balance is used to obtain force measurements in conjunction with the floor mount model support systems. This work package includes both single strut and three strut supports with pitch linkages or actuators to provide pitch angle positioning and a turntable to provide yaw angle positioning. This work package includes the interface support structure, lift mechanism, and any latching mechanisms required between the external balance and rolling plenum and external balance and floor mount test section. The external balance is a highly accurate advanced technology balance, mounted in the plenum area, under the test section floor. A lifting mechanism is provided for balance removal. Calibration of the external balance is covered in Section 1.3.7.6. The floor mount model support systems include the following sub-elements: Pitch Mechanism, Yaw/Turntable Mechanism, Walls/Actuation System, Drive System, Alignment & Latching Mechanism, Sealing System, Auxiliary Systems, Controls & Data Acquisition System, External Balance.

**Requirements:****Floor Mount Model Support System:**

One floor mount model support system and one external balances are required for the TSWT. The floor mount model support system and external balance shall be transportable as an integral unit between the build-up area and test section. The external balance is raised when the floor mount test section is moved and lowered when the external balance is in the installed position. It interfaces with a steel foundation permanently mounted in the movable plenum. Pitch motion and yaw positioning is required. Roll positioning is not required. Efforts must be made during the design process to insure adequate stiffness in the balance support structure.

**External Balance:**

The external balance shall fit into the TSWT plenum area. The external balance shall have the following characteristics: Automatic component decoupling by computer, real time acquisition

of measured values, frame ground support which is 100 times the flexural stiffness, and no wear. The external balance shall have design loads, accuracy, repeatability, and resolution requirements as shown in the design criteria, with the interchangeable cart concept.

**Criteria:**

**Table 1.5.2.5.a TSWT External Balance Criteria**

Parameter	Requirement	
Standards	Model Design Criteria	
Model Loads	See Table 1.5.g	
Positioning Requirements	See Table 1.5.h	
External Balance Accuracy Requirements	Accuracy, %	Repeatability, %
Lift	0.02	0.007
Drag	0.01	0.002
Side Force	0.05	0.017
Pitching Moment	0.02	0.007
Rolling Moment	0.05	0.017
Yawing Moment	0.05	0.017
Deflection/Stiffness Criteria	TBD, Ref.: Aeroline Study	
Blockage Criteria	TBD, Ref.: Aeroline Study	
Space Requirements	TBD, Ref.: Aeroline Study	
Installation/Removal Time	TBD, Ref.: Productivity Study	

**1.5.2.6 Test Support and Calibration Hardware**

**Definition:** The test support and calibration hardware includes the following sub-elements:

1.5.2.6.1 Calibration Hardware

1.5.2.6.2 Model Handling Equipment

1.5.2.6.3 Stings and Struts

1.5.2.6.4 Internal Balances

**1.5.2.6.1 Calibration Hardware**

**Definition:** Calibration hardware is the instrumentation and test hardware required to measure flow quality in the TSWT.

**Requirements:** A means of measuring flow quality shall be provided. The following types of flow quality measurements will be made over the entire test section area to within one foot of all walls, floors, ceilings and fillets:

Mach Number  
Turbulence Levels  
Flow Angularity

Total Pressure  
Total Temperature  
Acoustic Data  
Boundary Layer Profiles

The measurement devices shall provide the means for supplying time averaged data values, as well as instantaneous data values. All measurement devices shall be designed for use over the entire range of tunnel operation. No model or sting will be in the tunnel during calibration measurements. The calibration measurements shall be integrated into the tunnel data acquisition system.

In addition to measuring the flow data, a means of surveying the test section shall be provided. This system shall be capable of positioning the measuring devices very accurately and shall be fully automated such that the time to complete a survey is optimized. The specific requirements for the calibration devices are *TBD*.

**Criteria:** This hardware will be designed in accordance with the Model Design Criteria. Specific instrumentation, materials, etc., are *TBD*.

#### 1.5.2.6.2 Model and Sting Handling Equipment

**Definition:** Model and sting handling equipment is needed in the various build-up bays to support and transport the model components until they are mounted to the sting, strut, etc. The cart will be used to place models into the individual test sections, and to remove the models from the test section after completion of the test(s).

**Requirements:** The handling equipment shall consist of a cart type device with a lifting capability. A cart shall be provided for each build-up area. Each cart shall have the capability of supporting sting mounted models up to a 20 foot span and a weight of 2000 lb, and stings up to 20 foot overall length and a weight of 25,000 lb.

**Criteria:** *TBD*

#### 1.5.2.6.3 Stings and Struts

**Definition:** The TSWT will accommodate a variety of models and mounting options, including stings, struts, rod supports, and floor or wall semi-span model mounts. An assortment of stings, struts, and other mounting hardware items adequate for activation will be provided.

**Requirements:**

For model loads see section 1.5

- Stings: Two sting configurations shall be provided. The stings shall mount either to the pitch strut or to the pitch strut roll mechanism through a common joint. The distance from the model pitch point to the pitch strut is *TBD*. Two stings of each size shall be provided to

allow for model build-up activities while testing is underway for a total of four stings. Multiple adapters shall be provided to accommodate known user furnished balances and to provide for model positioning in the test section. The number of adapters required is *TBD*. One adapter specially designed to handle large mass flow rates of propulsion simulation air (See Table 1.4.f).

- **Struts:** Two floor mounted strut systems are required for external balance testing. The single strut design shall incorporate air lines for propulsion simulation testing with Turbine Powered Simulators (TPS) or ejectors, and balance and/or sting mounting provisions. The air lines shall be sized for the specified propulsion simulation air requirements (See Table 1.5.f), and shall have passages for multiplexed data cables, balance cables, model utilities, etc. The triple strut support system shall have similar capability to the single strut, with activation of the aft strut to provide angle of attack capability, and will mount either to a solid floor insert or to a turntable. Both struts shall be rated to full model loads (See Table 1.5.g) with "infinite" fatigue life.
- **Semi-Span Model Mount:** The removable floor mount hardware shall include the turntable plate, blanking plates, and the balance adapter assembly. Any other components required to provide a common mounting interface between the external balance and semi-span models shall be included in this item.

**Criteria:** Each system will be designed in accordance with the Model Design Criteria. Other criteria is *TBD*.

#### 1.5.2.6.4 Internal Balances

**Definitions:** Internal balances are load measuring devices mounted inside of models to accurately determine aerodynamics forces on the model.

**Requirements:** For the TSWT, two high-range balances and two low-range balances shall be provided. Dummy balances of each balance type and size shall also be provided, with the same load range rating. The dummy balances shall have the same physical outline as the active balances. All taper gages, ring gages, etc. required to assure balance fit shall be supplied.

The high range TSWT balance shall have the load range specified in Section 1.5.g for the closed jet test section. The load range for the low-range balances is *TBD*. The balance accuracy requirements for the two load ranges are *TBD*

**Criteria:** The internal balances and any dummy balances intended as test articles will be designed and built in accordance with the Model Design Criteria.

#### 1.5.2.7 Shuttle Cart

**Definition:** The shuttle cart is a general purpose lifting and handling device. It is used to move various test sections and model support systems from bay to bay in the Model Preparation

**Building.** The shuttle cart includes the following sub-elements: Structural Frame, Drive Mechanism, Lift System, Auxiliary Systems, Controls System.

**Requirements:** The shuttle cart shall have the capacity to lift any of the test sections or model support systems and have the capability of accurately translating and positioning a load vertically up to 10 ft. The preparation hall shuttle cart is self powered and has the capability to operate independently of the rail system. One shuttle cart

**Criteria:**

- Standards: *TBD*
- Rate of Travel *TBD*
- Lift Capacity *TBD, Design Process*
- Payload Positioning Accuracy: *TBD*

#### 1.5.2.8 Acoustic Test Section

**Definition:** The Acoustic Test Section provides an acoustically absorbent environment with sufficiently low background noise for the Mach Number range from  $M=0.4$  to 0.9 to enable acoustic testing of propulsion systems. Although primarily used for semi-span propulsion models, the acoustic test section also has the capability to use a 'standard' rear sting model for special tests.

**Requirement:** The flow quality requirements for the acoustic test section shall be the same as for the aerodynamic test sections (See 1.5.d). The walls of the acoustic test section shall absorb at least 90% of the incident acoustic field. The test section shall operate for the entire tunnel operating envelope.

**Criteria:** The background noise level for the acoustic test section is shown in Section 1.5. The background noise level requirement was based on the assumption that wall or model mounted transducers would be used, thus the fluctuating pressure field produced by the turbulent boundary layer in the test section determines the background noise floor. The noise field incident to the test section should be less than 95 dB. Details of acoustic treatment are *TBD* during the acoustic test section development studies and the final design.

#### 1.5.2.9 Acoustic Test Section Semispan Model Support System

**Definition:** The acoustic test section semi-span model support system will support a propulsion model throughout the operating range of the tunnel. Provisions to supply the model with high pressure air will be incorporated into the model support system design.

**Requirement:** All model support system wetted surface area shall be treatable with acoustically absorbent material.

**Criteria:** *TBD***1.5.3 Tunnel Internal Systems**

**Definition:** The tunnel internal systems include all components internal to the stationary pressure shell provided for the purpose of controlling the air flow quality in the wind tunnel. Included systems are the turning vanes, heat exchanger, settling chamber liner, high speed diffuser liner, honeycomb, turbulence attenuation screens, tunnel cleaning system, compressor foreign object debris (FOB) system, acoustic baffle section, choke section, and the flexible nozzle.

**Requirement:** Internal system elements shall maintain flow quality throughout the circuit such that test section flow quality requirements are satisfied.

**1.5.3.1 Turning Vanes**

**Definition:** Each 90-degree corner in the TSWT circuit is equipped with turning vanes to turn the direction of the mean flow for minimum corner dynamic pressure loss and highest possible flow quality. The turning vane system includes: (1) vertical turning vanes in corners 1, 2, 3, and 4; (2) attachment brackets, which are attached to mounting pads provided on the inside of the tunnel shell; and (3) personnel access to the turning vanes for maintenance and inspection.

**Requirement:** The turning vane cross sectional shape shall be optimized to maximize aerodynamic efficiency of the turning vane itself. Efficiency shall include, but is not limited to, complete turning of the flow in the corner at a minimum pressure loss and fully attached flow over the entire surface of the vane. The trailing edge of each turning vane shall be aligned to within 1-degree of the specified offset to the duct centerline axial direction. Each turning vane corner assembly shall be an integral unit complete with splitter vanes and access doors. It may be necessary to acoustically treat one or more turning vanes to preclude the fan drive fan noise from reaching the test section. The turning vanes shall be supported by the pressure shell by radial expansion type connectors.

**Criteria:**

Table 1.5.3.1.a TSWT Turning Vane Criteria

Parameter	Requirement
Standards	<i>TBD</i>
Allowable Pressure Loss	<i>TBD</i> (Aerolines Study)
Gap to Chord Distance Ratio	<i>TBD</i> (Experimental Verification)
Flow Conditions At Entrance:	<i>TBD</i> (Aerolines Study)
Dynamic Pressure (max.)	<i>TBD</i> (Aerolines Study)
Turbulence Levels (max.)	<i>TBD</i> (Aerolines Study)
Required Flow Quality At Exit:	
Turbulence Levels (max.)	<i>TBD</i> (Aerolines Study)
Structural Design	
Design Standards	<i>TBD</i>
Design Safety Factors	<i>TBD</i>
Design Fatigue Life	Infinite
Allowable Deflections (max)	<i>TBD</i>
Natural Frequency (min)	<i>TBD</i> (Design Analysis)
Materials	<i>TBD</i>
Shape; Leading and Trailing Edge Treatment	<i>TBD</i>
Acoustic Treatment Materials	<i>TBD</i>

### 1.5.3.2 Heat Exchanger

**Definition:** The tunnel air is cooled by an air to water heat exchanger located in the tunnel circuit. The physical location and configuration of the heat exchanger in the circuit are *TBD*. The function of the heat exchanger is to remove energy introduced by the fan and provide some temperature control. This work package includes the internal heat exchanger plus all associated supply and return piping, headers and expansion joints inside the tunnel. It also includes control valves, stabilizing tanks, immersion heaters (if required), and controls. Attachment brackets for the heat exchanger support structure, and circular fairings covering the gap between the inner diameter of the tunnel shell at the upstream and downstream ends are also included in this work package. It does not include the cooling tower, cooling tower controls, circulating pumps, or cooling water piping outside the tunnel (WBS 1.3.5). This work package also does not include tunnel penetrations (WBS 1.5.1.3). The heat exchanger is divided into the following sub-elements: Modular Tube Bundle Assembly, Tube Bundle Support Structure, Supply and Return Manifolds, and Heat Exchanger Control System.

**Requirements:** The heat exchanger shall be sized to remove sufficient energy to limit the operating temperature to a maximum of ambient plus 30 degrees F, for all operating conditions. The heat exchanger shall be designed for acceptable pressure losses and minimal flow disturbances for the air side. The flow quality requirements are specified below. The heat exchanger system shall contain features to control both the spatial and temporal uniformity of the temperature in the test section in order to meet specified flow quality requirements. One such feature is to use alternating flow directions in adjacent tubes to improve temperature

uniformity across the test section. Tradeoff studies are required in order to optimize the tube/fin geometry, to evaluate the need for elliptical shaped tubes to minimize flow disturbances as the air passes through the heat exchanger, and to evaluate the number of cooling passes required.

Consideration shall be given to accessibility of the heat exchanger hardware for maintenance and repair. Also, to facilitate maintenance and repair, the heat exchanger coil shall be designed and built as modular units. The heat exchanger design must be compatible with the cleaning system proposed in WBS 1.5.3.7. The heat exchanger must fit within the geometrical constraints given with supply and return headers and as much support equipment as possible located outside the flow boundary.

The heat exchanger support frame shall provide a rigid structure for mounting the tube bundle modules. The structural stiffness of the support frame and tube bundle assembly shall be sufficiently large to avoid any potential first mode flow excitation frequencies. Aerodynamically shaped fairings shall be used, where practical, to minimize flow disturbances. Consideration must be given to the thermal expansion throughout the operating range, in particular the differential expansion between the coil and the support structure.

The cooling water system shall contain the necessary expansion/surge tanks, flexible joints, throttling valves, automatic aeration equipment, automatic drainage/freeze protection system and other features to guarantee safe and reliable operation. The internal cooling water system connects to the forced draft cooling tower water distribution system described in Section 1.3.4.

Special considerations must be made to the overall system reliability requirements. Predictive maintenance techniques and other reliability enhancement features, such as redundant sensors, shall be used to minimize unscheduled downtime. The control system shall be compatible with the integrated controls and data acquisition requirements, described in Section 1.5.5.2.

#### Criteria:

Table 1.5.3.2.a LSWT Heat Exchanger Criteria

Parameter	Requirement
Standards: <i>TBD</i> -	Design
Total Heat Removal Capacity:	<i>TBD</i> , Ref.: Aerolines Study
Air Stagnation Pressure:	75 psia
Total Air Mass Flow Rate:	<i>TBD</i> - Studies
Total Heat Exchanger Flow Area:	<i>TBD</i> - Design
Maximum Air Temperature Entering Coil:	<i>TBD</i> - Design
Maximum Air Side Pressure Drop Across Coil:	<i>TBD</i> - Design
Minimum Water Flow Rate:	<i>TBD</i> - Design
Minimum Water Temperature Entering Coil:	<i>TBD</i> - Design
Maximum Water Temperature Exiting Coil:	<i>TBD</i> - Design
Maximum Water Pressure Loss:	<i>TBD</i> - Design
Maximum Waterside Operating Pressure:	<i>TBD</i> - Design
Heat Exchanger Efficiency:	
At Start:	<i>TBD</i> - Design
Nominal:	<i>TBD</i> - Design
Before Required Cleaning:	<i>TBD</i> - Design
Waterside Fouling Factor:	
At Start:	<i>TBD</i> - Design
Nominal:	<i>TBD</i> - Design
Before Required Cleaning:	<i>TBD</i> - Design
Airside Fouling Factor:	
At Start:	<i>TBD</i> - Design
Nominal:	<i>TBD</i> - Design
Before Required Cleaning:	<i>TBD</i> - Design
Air Temperature Requirements:	
Spatial:	See Tables 1.5.a & Table 1.5.d
Temporal:	<i>TBD</i> - Studies
Flow Quality Requirements:	See Table 1.5.d
Fin/Tube Geometry:	<i>TBD</i> - Experimental Tests
Heat Exchanger Materials:	<i>TBD</i> - Design

### 1.5.3.3 Settling Chamber Liner

**Definition:** The settling chamber liner forms the aerodynamic surface of the TSWT from the entrance of the wide angle diffuser to the start of the flexible nozzle. This package includes mounts for flow conditioning components located in the settling chamber as well as structural framing required to mount the liner to pressure vessel shell attachment points.

**Requirement:**

The settling chamber liner shall withstand all structural and aerodynamic loads over the entire TSWT operating envelope. The settling chamber liner shall have penetrations through it on either side of each honeycomb and screen element sections. The penetrations are required for personnel access for routine maintenance, inspection, repairs and cleaning of the settling chamber flow conditioning elements. The accesses shall not protrude significantly into the flow stream, such that flow disturbances are created. The accesses shall not cause the test section flow quality to be out of tolerance.

The wide angle diffuser shall include a screen or other suitable pressure drop device sufficient to maintain fully attached flow inside the diffuser.

**Criteria:**

- Standards: *TBD*
- Geometry: *TBD, Ref.: Aeroline Study*
- Materials: *TBD, Design*
- Manufacturing Tolerances: *TBD, Design*  
   Machining Requirements  
   Surface Finish Requirements

**1.5.3.4 High Speed Diffuser Liner**

**Definition:** The high speed diffuser forms the flow surface from the exit of the isolation valve downstream of the test section to entrance of the conical diffuser section, providing a transition from rectangular to round cross section.

**Requirement:** The geometry of the high speed diffuser shall be optimized for maximum static pressure recovery. A maximum of 5.5 degree total expansion angle is recommended.

**Criteria:**

- Standards: *TBD*
- Geometry: *TBD, Ref.: Tunnel Aerolines*
- Materials: *TBD, Design*
- Manufacturing Tolerances: *TBD, Design*
- Machining Requirements: *TBD, Design*
- Surface Finish: *TBD, Design*

### 1.5.3.5 Honeycomb

**Definition:** The honeycomb is used primarily to attenuate lateral and vertical components of flow turbulence to a level required to meet the flow quality requirements in the test section.

**Requirement:** The honeycomb shall be sized to reduce lateral and vertical turbulence levels and flow angularity to a level required to meet the test section flow requirements (See Table 1.5.d). The honeycomb structure shall also be required to support aerodynamic loads encountered in any portion of the LSWT operating envelope. Personnel access to either side of the honeycomb is required for routine inspections, cleaning, repairs, and maintenance. The honeycomb support frame shall provide a rigid structure for mounting the honeycomb. The structural stiffness of the support frame assembly shall be sufficiently large to avoid any potential first mode flow excitation frequencies. Aerodynamically shaped fairings shall be used, where practical, to minimize flow disturbances. Consideration must be given to the thermal expansion throughout the operating range.

**Criteria:**

- Standards: *TBD*
- Flow Quality: *TBD, Aeroline Study*
- Aerodynamic Loads: *TBD, Aeroline Study*
- Honeycomb Geometry:
  - Cell Size: *TBD, Design*
  - Thickness: *TBD, Design*
  - L/D Ratio: *TBD, Design*
- Honeycomb Material: *TBD, Design*
- Honeycomb Support Structure Design: *TBD, Design*
- Allowable Pressure Drop: *TBD, Aeroline Study*

### 1.5.3.6 Turbulence Attenuation Screens

**Definition:** Turbulence screens reduce the longitudinal level of flow turbulence to a level required to meet test section flow quality requirements. The number of screens, spacing, mesh and wire sizes will be determined primarily on turbulence reduction basis. The screen mounting method, minimum size of screen wire, and to some degree, the screen mesh size will be determined by aerodynamic loads considerations.

**Requirement:** Open area for the screen in the settling chamber shall be larger than 57%. The spacing of the screens in the settling chamber shall be such that maintenance personnel can access either side of the screen to perform routine inspections, cleaning, repairs, and

maintenance. The personnel access shall not require the removal of any screens. The spacing shall also allow for the rigid installation and erection of the tunnel cleaning and inspection system. The screen support frame shall provide a rigid structure for mounting the screens. The structural stiffness of the support frame assembly shall be sufficiently large to avoid any potential first mode flow excitation frequencies. Aerodynamically shaped fairings shall be used, where practical, to minimize flow disturbances. Consideration must be given to the thermal expansion throughout the operating range.

**Criteria:**

- |   |  |
|---|--|
| • Standards:                                | <i>TBD</i>                                       |
| • Screen Size, Porosity, and Effectiveness: | <i>TBD</i> , Aeroline Study                      |
| • Aerodynamic Loads:                        | <i>TBD</i> , Aeroline Study                      |
| • Allowable Pressure Drop:                  | <i>TBD</i> , Aeroline Study                      |
| • Screen Material:                          | <i>TBD</i> , Design                              |
| • Acceptable Screen Joint:                  | Butt Welds Only                                  |
| • Number of Screens:                        | <i>TBD</i> , Plus Provisions for 1 Future Screen |

### 1.5.3.7 Tunnel Cleaning System

**Definition:** The tunnel cleaning system will provide a means of cleaning all of the internal components of both wind tunnels. These components include (but are not limited to) the turning vanes, heat exchanger, screens, honeycomb, fan blades, and baffles (if required).

**Requirements:** The cleaning system shall consider access to all elements requiring routine inspection and cleaning. The cleaning system shall be such that it can be removable or at least retracted out of the flow stream during tunnel operation. The cleaning system shall be able to be installed in under 15 minutes at any location and removed within 15 minutes at any location. The cleaning system shall not leave any substantial residue or fluid in the tunnel circuit at the conclusion of a cleaning evolution.

**Criteria:** *TBD*

### 1.5.3.8 Compressor Foreign Object Debris (FOD) Screen

**Definition:** A screen section on or just upstream of the turning vane set # 2 that protects fan blades from debris. This screen section, a coarse mesh screen, may or may not extend the full height of the cross section.

**Requirement:** The foreign object debris (FOD) screen shall be designed based on the expected sizes and momentums of debris from failed models and tunnel components. Simultaneously, the FOD shall be designed for minimum flow total pressure loss.

**Criteria:**

- Standards: *TBD*
- Allowable Pressure Loss *TBD, Aeroline Study*
- Projectile Definition:
  - Projectile Sizes: *TBD*
  - Projectile Shapes: *TBD*
  - Projectile Weights: *TBD*
  - Max Kinetic Energy To Be Absorbed (ft-lbs) *TBD*
- Screen Material, Mesh Size, Wire Size, and Porosity *TBD, Design*
- Acceptable Screen Joints: *Butt Weld Only*
- Screen Absorption Capability: *TBD*

### 1.5.3.9 Choke Section

**Definition:** The choke section is a tunnel condition control device which is located downstream of the tunnel test section.

**Requirements:** The tunnel choke shall be capable of providing area reduction of the tunnel flow area such that the sonic condition can be reached at this location for tunnel test section Mach Numbers at or below  $M=0.95$  for all tunnel pressures and temperatures.

**Criteria:** *TBD*

### 1.5.3.10 Flexible Nozzle

**Definition:** The tunnel flexible nozzle is the section of the circuit just upstream of the tunnel test section which allows operation of the tunnel to supersonic Mach Numbers by adjustment of the area ratio. The nozzle sidewall positions are typically adjusted by actuators or jacks behind the walls.

**Requirements:** The flexible nozzle shall provide the capability to achieve the proper area ratio for  $M=1.5$  operation in the TSWT test section. Nozzle movements shall be within the productivity requirements for the facility (nozzle movement times *TBD*)

**Criteria:** *TBD*

#### 1.5.3.11 Acoustic Baffle Section

**Definition:** The latest concept for the tunnel included a bulk acoustic silencer or baffle section consisting of longitudinal parallel sections of acoustic material within a metal framework. The need and configuration of this element is to be determined as part of the study effort

**Requirements:** The inflow noise to the test section shall be below the frequency/magnitude ranges specified in the tunnel test section element.

**Criteria:** *TBD*

#### 1.5.4 Compressor And Drive System

**Definition:** The TSWT Compressor and Drive System provides the shaft power and the compressor which produces TSWT air flow. The primary components are the motors, motor controls, axial compressor (fan), and drive system auxiliaries. The motor feed current is provided by the yard Electrical Power System (Section 1.1.4.).

The motors interface with the Drive Motor Controls (1.5.4.3) at the closest physical connection point to the motors. The drive motor foundations are included in 1.2.2.3, LSWT/TSWT Drive Building. The axial compressor rotor will interface to the drive motor at the parting surface of a coupling flange closest to the TSWT pressure shell. A common flange configuration is required for all drive motor and compressor couplings, if feasible. The coupling hardware (bolts, pins, etc.) are included in the 1.5.4.1. and 1.5.4.3 definition. The motors and compressor includes *TBD* type bearings to support each end of their respective rotor shafts. The interface surface between bearings and shafts is defined as the surface of rotation, i.e. the rotating shaft is part of the shaft and the stationary bearing surface is included in the bearing package. The Compressor and Drive System includes the following sub-elements: 1.5.4.1. Drive Motors, 1.5.4.2. Drive Motor Controls, and 1.5.4.3. Axial Compressor and Case, and 1.5.4.4 Drive System Auxiliary Systems.

**Requirement:** High value equipment protection and reliability of total system performance are the major design requirements. Common design features and interchangeable equipment shall be used to the maximum extent practical throughout the NWTC. The design Mach/total pressure point coupled with maximum Mach Number required will determine the design pressure ratio for the compressor. The acoustic requirements are expected to be a major factor in the compressor (fan) design, tending to push for low tip mach number, highly uniform compressor inflow, and greater spacing than traditional between rotating blades and non rotating elements (i.e. stators, vanes, supports, etc.).

The Compressor and Drive System shall be designed as an integrated system with trade studies which consider design risk (assured reliable life cycle operation over the full range of test conditions required for TSWT), energy efficiency and reduced acoustic levels as key criteria in the determination of specific design requirements for its sub-systems and components.

To the maximum extent practical, the components and subsystems used throughout the NWTC shall be of common design and interchangeable. The physical location of all equipment shall be such to facilitate maintenance and handling functions. Unless impractical, all bearings and couplings in 1.5.4.1 and 1.5.4.3 are required to be physically and functionally interchangeable. All bearings shall be designed with a means of continuing to provide lubrication and thus allow safe shutdown in the event of a lube system failure. The bearings are required to operate at the full range of TSWT conditions without loss of oil into the tunnel.

All drive train elements are required to transmit the full overload rating of the drive system on a routine basis. In addition, all drive train elements shall be capable of withstanding maximum torque load for emergency stops and/or maximum acceleration with no deleterious effects. The couplings and mating interface surfaces are to be of common design for all motor interfaces. The drive train / coupling design is required to allow for the thermal expansion, relative movement and vibrations between the drive motors and TSWT compressor.

Health monitoring and diagnostic instrumentation will be provided by the Predictive Maintenance System 1.5.5.5. Provisions for the integration of the 1.5.5.5 instrumentation shall be made during the detailed design of each appropriate component of 1.5.4. and included in the 1.5.4. requirements.

**Criteria:**

• Standards:	<i>TBD</i>
• Sync Speed	<i>TBD</i>
• Shaft Power vs. RPM	<i>TBD</i>
• Power Ramp Rates	<i>TBD</i>
• Drive Power Design Point	See Table 1.5.a
• Maximum Drive System Acceleration Rate (RPM/sec.)	<i>TBD</i>
• Maximum Drive System Deceleration Rate (RPM/sec.)	<i>TBD</i>
• Overall Drive System Reliability	<i>TBD</i>

#### 1.5.4.1 Drive Motors

**Definition:** The drive motors provide the compressor shaft power establish and maintain aerodynamic flow in the TSWT. The drive motors work package is broken into the following sub-elements: Rotors, Bearings, Couplings, Stators, and Coolers.

**Requirement:** The motor sizing and design are defined by the TSWT performance requirements and projected compressor design performance. The design continuous duty rating shall be 1.05 of the projected required shaft horsepower rating needed for the TSWT design point performance. An intermittent duty cycle is required at 1.20 the continuous duty cycle level for up to one hour with a subsequent one hour synchronous speed cool down period at or below the continuous duty cycle maximum power level. The TSWT motors shall be of common design, physically and functionally interchangeable to the extent practical with other large motors in the NWTC. Major components should be interchangeable to the extent practical based on Life Cycle Cost considerations. The motor, drive shaft, building and support equipment shall provide the ability to remove the main drive motor from the TSWT Main Drive Train, install a replacement motor and reestablish drive capability within 24 hours.

**Criteria:**

• Standards:	<i>TBD</i>
• Number and size of motors	<i>TBD</i>
• Voltage	<i>TBD</i>
• Output power vs. RPM	<i>TBD</i>
• Input power vs. load	<i>TBD</i>
• Continuous Duty Rating at Design Power Point	1.05
• Intermittent Duty Rating	1.20 of Continuous Duty Rating
• Duration of Intermittent Duty	1 hour Synchronous Speed
• Bearing Type	<i>TBD</i>
• Cooling System Capacity (hp)	<i>TBD</i>

#### 1.5.4.2 Drive Motor Controls

**Definition:** The drive motor controls provide the variable frequency start system and sub synchronous speed control system for the TSWT Drive Motors, 1.5.4.1. The major components of the system includes the switch gear, harmonic filters and redundant power conditioning and directly related equipment. A major portion of the equipment may be located outdoors in the Station No. 1 area adjacent to the main subststion (Section 1.1.4).

The Drive Motor Controls system receives input power from the power conversion equipment in the Yard Electrical Power System, Section 1.1.4. The power input interfaces at the first physical connection point inside the initial enclosures. The output interface is the physical connection to

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the motors. The demand/set point control input to this equipment comes from Section 1.5.5.2 with the output signal being routed to the appropriate location for input to this equipment.

The drive motor controls work package is broken into the following work packages: Switch Gear, Harmonic Filters, Power Conditioning Equipment, and Related Equipment.

**Requirement:** The primary design requirement is to accelerate to any desired speed above 5% of synchronous speed and maintain that speed  $\pm 1$  rpm indefinitely. The architecture shall provide for a flexible system which is sufficiently interconnected and equipment positioned to allow maximum ability to continue test operations during equipment repair and maintenance periods. Consideration of collateral damage minimization from potential failure modes shall be design criteria for equipment location and physical arrangement. A robust design, reliable and efficient operation and long term assured technical and spares support are significantly more important than minimum initial cost. All equipment must be provided with environmental protection and sufficient environmental conditioning consistent with its location to ensure reliable operations and most economical life cycle cost.

Criteria:

- |   |            |
|---|------------|
| • Standards:  | <i>TBD</i> |
| • Ramp time to any speed                              | <i>TBD</i> |
| • Speed stabilization time                            | <i>TBD</i> |
| • Power requirement                                   | <i>TBD</i> |
| • Number and size of components                       | <i>TBD</i> |
| • Speed Control Accuracy<br>(Above Synchronous Speed) | +/- 1 RPM  |
| • Speed Control Accuracy<br>(Below Synchronous Speed) | <i>TBD</i> |

**1.5.4.3 Axial Compressor and Case**

**Definition:** Provides the TSWT primary axial flow compressor shaft; structural mounting discs for the rotating blades; the rotating blades; non-rotating blades, supports and vanes; pressure shell section at the compressor; flanges on the compressor shell for attachment to the rest of the pressure shell; all elements of the drive shaft (except motor elements); and all directly related fairings, seals and equipment. The blade and hub design shall readily allow repair and blade replacement to support high productivity. Provides 120% spare blades, 110% of the spares are to be manufactured after performance acceptance of the compressor installed in the TSWT.

The compressor nacelle provides the aerodynamically contoured shell (teardrop shape) around the compressor hub and a symmetric airfoil fairing is provided around the primary drive shaft. This fairing is needed to reduce separation, acoustic disturbances and shaft aerodynamic loads. The drive shaft fairing is expected to attach to the pressure shell at the drive shaft penetration and extend through the turning vanes to the nacelle fairing. The primary supports of the compressor both forward and aft of the rotor blades constitute the principal load path for the compressor loads. The aerodynamic and structural requirements for these components are major factors in the compressor design effort. The required seals and directly related hardware to make the nacelle an effective aerodynamic shape are included.

The rotating portions of the nacelle attach to the rotor shaft and the interface is at the removable joint closest to the center of rotation with all fasteners provided with the fairings under this work package. The non-rotating portion of the nacelle will attach to the supports and provide the center body attachment for the stators/EGVs. The interface with movable or adjustable components will be at the removable joint which separates the movable surface from the stationary elements.

The compressor case provides the pressure shell, structural mounting rings, stators, and support vanes for the compressor. The compressor case interfaces with the pressure shell at mating flanges oriented perpendicular to the compressor axis of rotation. The mating surface flatness and alignment specifications shall be specified by pressure shell design of Section 1.5.1.3.

The stators/vanes interface with the nacelle, at the movable interface to the fixed surface, with all mounting hardware and fittings are provided by this work package. This package provides all design provisions for integration and installation of the position indicators and structural instrumentation for the components included herein. The sensors and related instrumentation for the blade position, rotor speed and other control parameters will be provided by Section 1.5.5.4. and integrated into the TSWT Process Instrumentation System. The axial compressor/case includes the following sub-elements: Rotor shaft/hub, all drive shaft components except those with the drive motors, Rotor blades, Rotor bearings, Bearing supports, Seals, Stators and vanes, and Fairings.

**Requirement:** The design and integration of the Axial Compressor and Case elements must accomplish the acoustic, aerodynamic and energy efficient requirements and objectives of the TSWT. They shall also provide maintenance and operational concepts which support long term productivity and life cycle cost objectives. Fail-operate provisions shall be incorporated in all controllable surfaces to the extent practical. Fail-safe provisions shall be provided. All adjustable and controllable components shall include sufficient position indicators to record compressor configuration during all operation via the TSWT Process Instrumentation, 1.5.5.4. Required instrumentation provisions for health monitoring and Predictive Maintenance System inputs shall be interfaced with 1.5.5.5. Requirements for low turbulence and acoustic testing demand greater than normal care in the aerodynamics contouring of all air-stream surfaces and fairings. The design and fabrication approach are likely to be affected by the need for tolerances which are unusually stringent.

The compressor case shall be able to contain the rotor blades in the event of a catastrophic failure as well as meet the pressure requirements of the pressure shell. The compressor case shall meet the pressure shell requirements specified in Section 1.5.1.3.

Maintenance and accessibility require special considerations to meet productivity requirements. The compressor case section shall provide a compressor access maintenance door, which will allow for rapid access to the rotor and stator blades. The access shall be sufficient to allow for removal and installation of rotor and stator blades. The access door is required to operate at all pre and post operational shell temperatures and shall open or close in no more than 15 minutes on a routine basis. Removable hatches are required directly over the compressor bearings of sufficient size to allow bearing removal. Fixtures and tools to support bearing assembly and replacement are included.

This work package will provide five (5) instrumented blades which have been calibrated to provide maximum bending and torsion stresses. The instrumentation provisions to provide eight channels of strain gage data to the tunnel shell are also included in this work package. These data channels will be interfaced with 1.5.5.5. (Predictive Maintenance System) external to the compressor shell. Only limited physical interface with the nacelles and supports, and the stators/EGVs are expected but seals, critical tolerances and integral design requirements for compressor performance will require extensive interface during the design and installation of the compressor. The lubrication and cooling requirements shall be provided with the interface point at the bearing penetrations for lift/lube oil connections.

The drive shaft shall not have any first mode frequencies that are less than at least twice the maximum shaft rotational speed.

**Criteria:**

• Standards:	<i>TBD</i>
• Required Performance (Airflow, pressure ratio and stall margins)	<i>TBD</i>
• Bearing loads and torques	<i>TBD</i>
• Operating temperatures	<i>TBD</i>
• Number & spacing of primary elements (rotor blades, stators/vanes, support struts)	<i>TBD</i>
• Acoustic levels	<i>TBD</i>
• Materials:	<i>TBD</i>
• Pressure Shell	See Table 1.5.1.3.a

#### 1.5.4.4 Drive System Auxiliary Systems

**Definition:** This section includes the ancillary support systems required for the compressor drive system. The subsystems are the bearing lubrication sub-system, and the drive system cooling sub-system.

The bearing lubrication sub-system includes all pumps, pump motors, supply and return piping, filters, headers, expansion joints, valves, instruments, tanks, immersion heaters, coolers, motor starters, switchgears, and controls. The interfaces are at the compressor shell, and at each pedestal for the bearings external to the tunnel shell (for the oil supply and return), and the power connection to the switchgear.

The drive system cooling sub-system consists of all headers, valves, supply and return piping, filters, controls, instruments, and boost pumps (if required). The sub-system provides cooling to the bearing lubrication sub-system, as well as the tunnel drive motors. The drive system cooling sub-system interface with the NSWC cooling system (Section 1.3.4) is **TBD**.

**Requirements:** The bearing lubrication sub-system shall be sized to provide at least 150% of the total manufactures required lubrication flow for all elements connected to the system. The system configuration (i.e. multiple dedicated units, single pump with single supply/return headers, etc.) is **TBD**. Consideration shall be given to the accessibility of all components in the bearing lubrication sub-system for maintenance and repair. Special considerations must be made to the overall system reliability requirements. Predictive maintenance techniques and other reliability enhancement features, such as redundant instrumentation, shall be used, when required to minimized unscheduled downtime. The control system shall be compatible with the integrated controls and data acquisition requirements, described in Section 1.5.5.2.

The drive system cooling sub-system shall be sized to provide at least 150% of the total manufactures required cooling flow for all elements connected to the system. The system configuration is **TBD**. Consideration shall be given to the accessibility of all components in the bearing lubrication sub-system for maintenance and repair. Special considerations must be made to the overall system reliability requirements. Predictive maintenance techniques and other reliability enhancement features, such as redundant instrumentation, shall be used, when required to minimized unscheduled downtime. The control system shall be compatible with the integrated controls and data acquisition requirements, described in Section 1.5.5.2.

#### Criteria:

##### Bearing Lubrication Sub-system Requirements

- |                              |            |
|------------------------------|------------|
| • Design Pressure            | <b>TBD</b> |
| • Maximum Design Temperature | <b>TBD</b> |
| • Minimum Design Temperature | <b>TBD</b> |

- Maximum Flow Rate *TBD*
- Lubrication Oil Type *TBD*
- Total Storage Capacity *TBD*
- Total Number of Pumps *TBD*

#### Drive System Cooling Sub-system Requirements

- Design Pressure *TBD*
- Maximum Design Temperature *TBD*
- Minimum Design Temperature *TBD*
- Maximum Flow Rate *TBD*
- Total Storage Capacity *TBD*
- Total Number of Pumps *TBD*

### 1.5.5 Electrical, Controls And Data Acquisition System

#### 1.5.5.1 Low Voltage Electrical System

**Definition:** Provide the low voltage electrical system for the TSWT.

**Requirement:** The low voltage electrical system shall provide 480 volt and lower electrical systems including secondary switchgear and load centers; 480 volt motor control centers, power distribution panels; DC system equipment with batteries, chargers, distribution panels, and motor control; and wiring and cable tray/conduit systems. Also included is the raceway complex for the control and the data acquisition systems.

#### 1.5.5.2 Controls System

**Definition:** Controls system includes all electrical/electronic components, cabling, and software necessary to control tunnel processes and subsystems listed below for the TSWT. This section does not include sensors, actuation devices, or power sources/controllers for the actuation devices.

**TSWT Control Processes and Subsystems**

Compressor speed	Compressor blade angle	Inlet & aft vane angles
Tunnel pressure/vacuum	Tunnel humidity	Plenum pressure
Tunnel temperature	Test section side walls	Trim flaps
Test section isolation	Model attitude	Choke fingers
Model engine	Model control surfaces	Stator blade angle
Pressure probe	Interlocks	Nozzle contour
Model propulsion		

**Requirements:** Integrated controls and test data acquisition systems are utilized in both tunnels. They provide automated execution of test sequences, automated start up and shut down of auxiliaries, and comprehensive tunnel process monitoring with diagnostics. The system shall be designed to accommodate any single point of failure without facility damage or personnel harm. Sensors supplying test data and process data are shared where practical and pre-run calibrations are utilized in addition to selective redundant sensors to maximize tunnel availability. Separate control rooms and control systems for each tunnel are specified to minimize down time and eliminate possible security issues. Operator interfaces consist of workstations (x-window terminals) with uniformity of displays and operational procedures between tunnels. Operators have three levels of control authority which consist of coordinated control of tunnel processes, control of set points to individual processes, and control of actuation devices.

**Criteria:**

- System availability ***TBD***
- Control ranges of processes ***TBD***
- Accuracies of processes at steady state conditions ***TBD***
- Maximum rates of change of processes ***TBD***
- Transient responses and settling times of processes ***TBD***

**1.5.5.3 Data Acquisition System**

**Definition:** The data acquisition system includes the following sub-elements:

Tunnel Parameter Data System  
 Data Acquisition Control Processor  
 Data Processing Workstations  
 Data Analysis Workstations  
 Development and Simulation  
 Data Archive File Servers  
 Data Analysis Rooms  
 Communications

Test Instrument Cart  
Test Static Data System  
Dynamic Pressure Data System  
Hot Wire Anemometer Data System  
Acoustic Data System

### **Tunnel Parameter Data System**

**Definition:** This system acquires data from various locations around the tunnel circuit. Measurements are predominantly temperatures, dew point, pressures, and positions needed for test or control functions.

**Requirements:** This tunnel parameter data system shall acquire the data, compute engineering units, and coefficients, perform some limit checking and alarming, and make the data available via high speed networks to the tunnel control and facility management processors. Trend and historical performance data are archived for later analysis. Data are also passed to the data acquisition control processor for synchronization with the test or research data and for real-time display.

Most pressure data is acquired through an electronic pressure scanning system (ESP) with a capability of scanning up to 1000 pressure channels. The data acquisition unit shall have the capability of scanning up to 256 analog channels and 24 general purpose digital channels. The data acquisition unit shall allow programmable settings for filter selections and variable gain settings on an individual channel basis.

### **Criteria:**

Data Acquisition Unit:

Active Filters:

Up to 4 programmable settings per channel - ranges: *TBD*  
Filter Characteristics: 4 pole Butterworth or Bessel *TBD*

Signal Conditioning:

Channel Count Requirements: *TBD*  
Variable Transducer Supply Excitation Voltage Range: *TBD*  
Bridge Completion Characteristics: *TBD*  
Modes Supported: strain gage, thermocouple, RTD

Amplifier characteristics:

Amplifier Per Channel  
Input Impedance: greater than 10 megohm  
Common Mode rejection: 120 db minimum  
Gain Ranges: 12 minimum, covering 5 mv. up to 10 volt, FS

**Additional Features:**

Programmable Sampling Rate: *TBD*  
Automatic Calibration Capability: *TBD*  
Automatic Zero Capability: *TBD*  
Overall System Accuracy and Noise: *TBD*

**Computer Subsystem:**

Standards: appropriate federal open systems standards *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*  
Bus Architecture: *TBD*

**Peripherals:**

Fixed Disk: Size, transfer rate, format *TBD*  
Removable Disk: Size, transfer rate, format *TBD*  
Optical Disk: Size, transfer rate, format *TBD*  
Archive Tape: Size, transfer rate, format *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF,  
meeting appropriate standards for networking, portability,  
and other features *TBD*

Custom designed data acquisition, calibration, control, and real-time display software  
appropriate for meeting the acquisition and display requirements noted above *TBD*

**Data Acquisition Control Processor**

**Definition:** This system acquires test measurements from the test section or a cart bay area and the tunnel parameters processor.

**Requirements:** The data acquisition control processor shall acquire test measurements from the test section or cart area via a high speed fiber optics network from processors on the model cart. Information from the test section shall be synchronized with the tunnel parameter information, reduced to engineering units and coefficients, and passed through high speed networks to other data processing, analysis, and control systems. This processor shall also provide real-time display to the data acquisition system operator's console. This processor is required to handle the sequencing of all data acquisition related processes when commanded by the operator or by the

facility management processor and when test conditions are achieved. This processor also alerts the facility management processor when data has been acquired so that test conditions can be set for the next test point.

**Criteria:**

**Computer Subsystem:**

Standards: appropriate federal open systems standards *TBD*

Clock Rate: *TBD*

Processing Speed: *TBD*

Memory Cycle time: *TBD*

Memory Size: *TBD*

Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*

Bus Architecture: *TBD*

**Peripherals:**

Fixed disk: Size, transfer rate, format *TBD*

Removable Disk: Size, transfer rate, format *TBD*

Optical disk: Size, transfer rate, format *TBD*

Archive Tape: Size, transfer rate, format *TBD*

Hard Copy Units: *TBD*

X Terminal Characteristics: *TBD*

Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF, meeting appropriate standards for networking, portability, and other features *TBD*

Custom designed data acquisition, calibration, control, and real-time display software appropriate for meeting the acquisition and display requirements noted above *TBD*

**Data Processing Workstations**

**Definition:** These workstations receive test data for the data acquisition processor via a high speed network.

**Requirements:** The data processing workstations are required to process the test data on-line in near real-time for the test engineer's test console as well as other stations. Data shall be represented through a high end graphical user interface that will present data in a flexible, easy format that can quickly be changed by the engineer.

**Criteria:**

**Workstation Requirements:**

Standards: appropriate federal open systems standards *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle Time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*  
Bus Architecture: *TBD*

**Peripherals:**

Fixed Disk: Size, transfer rate, format - *TBD*  
Removable Disk: Size, transfer rate, format - *TBD*  
Optical disk: Size, transfer rate, format - *TBD*  
Archive Tape: Size, transfer rate, format - *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF,  
meeting appropriate standards for networking, portability,  
and other features *TBD*

Custom designed real-time display software appropriate for meeting  
the acquisition and display requirements noted above *TBD*

**Data Analysis Workstations**

**Definition:** These workstations provide near real time and off-line analysis capability.

**Requirements:** These workstations shall have high end graphics capability that can be used to readily compare current data with previous test conditions stored on the data archive file server. These displays shall be located near the test engineer's console and can be networked to the data analysis rooms.

**Criteria:****Workstation Requirements:**

Standards: appropriate federal open systems standards *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*

Bus Architecture: *TBD*

**Peripherals:**

Fixed Disk: Size, transfer rate, format - *TBD*

Removable Disk: Size, transfer rate, format - *TBD*

Optical Disk: Size, transfer rate, format - *TBD*

Archive Tape: Size, transfer rate, format - *TBD*

Hard Copy Units: *TBD*

X Terminal Characteristics: *TBD*

Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF meeting appropriate standards for networking, portability, and other features - *TBD*

Custom designed data analysis software appropriate for meeting the acquisition and display requirements noted above - *TBD*

Data Analysis Software Tools - Software for signal processing, visualization, data reduction, database management, and other features typically required for data analysis.  
Final Requirements - *TBD*

**Development And Simulation Processors**

**Definition:** The development and simulation processors are available to support development and operations functions without interfering with the daily operations of the tunnels.

**Requirements:** Functions that shall be supported by the development and simulation processors include data acquisition systems software development, controls systems software development, simulation, documentation support, hardware and software system checkout, test preparation, and software configuration control. One processor shall be provided for DAS support, one for controls, and a small file server for documentation and administrative services. These computers shall also be configured in such a fashion that they can serve as backup processors for other processors on the control room network.

**Criteria:**

**Computer Subsystems:**

Standards: appropriate federal open systems standards *TBD*

Clock Rate: *TBD*

Processing Speed: *TBD*

Memory Cycle time: *TBD*

Memory Size: *TBD*

Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*

Bus Architecture: *TBD*

**Peripherals:**

Fixed Disk: Size, transfer rate, format - *TBD*  
Removable Disk: Size, transfer rate, format - *TBD*  
Optical Disk: Size, transfer rate, format - *TBD*  
Archive Tape: Size, transfer rate, format - *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF, meeting appropriate standards for networking, portability, and other features *TBD*

Custom designed data acquisition, control, and real-time display software appropriate for meeting the acquisition and display requirements noted above *TBD*

**Computer Aided Software Engineering tools:**

Software to manage the design, integration, testing, and life cycle support for the data acquisition, control, data analysis, and other software required to operate and maintain all computer systems within the test facility. Final Requirements *TBD*

**Configuration Management Tools:**

Software tools to track, document, and manage configuration changes to software, hardware, cabling, instrumentation, etc. associated with the life cycle support of the facility.

Final Requirements *TBD*

**Data Archive File Servers**

**Definition:** These processors are the repository for test data as it is being acquired:

**Requirements:** Test data shall be stored on the data archive file servers. Tunnel process control data shall also be archived on a separate server for post test analysis. Previous test configuration data or theoretical predictions shall reside on this archive system so that they may be called up for analysis and comparison with the current test. Files shall be maintained in a secure environment to provide access only as required. Optical disk storage shall be provided for archiving large volumes for static and dynamic data, and high speed printers shall be provided.

**Criteria:****Data Archive Subsystem Requirements:**

Standards: appropriate federal open systems standards *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle Time: *TBD*

Memory Size: *TBD*  
Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*  
Bus Architecture: *TBD*

**Peripherals:**

Fixed Disk: Size, transfer rate, format *TBD*  
Removable Disk: Size, transfer rate, format *TBD*  
Optical Disk: Size, transfer rate, format *TBD*  
Archive Tape: Size, transfer rate, format *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Posix Operating System with X Window/MOTIF, meeting appropriate standards for networking, portability, and other features *TBD*

Configuration management and data base management tools as appropriate for the maintenance and archiving of large data sets of research and control system data. Database management software shall meet appropriate national standards Final Requirements: *TBD*

**Data Analysis Rooms**

**Definition:** Two rooms will be provided adjacent to the main control room for use by visiting test personnel during preparation, testing, and limited post test analysis.

**Requirements:** Both data analysis rooms shall be networked to the cart areas, the test section, and the main control room; however, each data analysis room shall be capable of isolation for classified tests so that only appropriate networks are active to support setup in a model preparation area or test section. Each analysis room shall have a file server for data archiving and analysis as well as several workstations and X terminals to support real-time data display, and analysis during setup, calibration, and checkout prior to tunnel entry. Video projection systems shall also be provided for displaying real-time or video from the test section.

**Criteria:**

**Video Projection System Requirements:**

Number of Display Stations: *TBD*  
Size of Display Stations: *TBD*  
Video Control System Requirements: *TBD*  
Requirements for Video Integration on X terminals: *TBD*

See appropriate sections included herein for X terminal, file server, data analysis workstations, and other requirements.

### **Communication Networks**

**Definition:** The communications networks are the high speed fiber optics networks that will be used extensively throughout the system.

**Requirements:** Since the system architecture uses a tiered, distributed system approach, communications networks will play a key role during systems operations. The proposed system shall offer support for LAN/Ethernet 802.3, FDDI, IEEE-488, RS 232/422, reflective memory fiber optic systems, and other technologies appropriate at the time of construction.

### **Criteria:**

Standards: appropriate federal open systems standards that are applicable to networks - *TBD*

### **Reflective Memory Network Subsystem:**

Transmission Media: *TBD*

Transfer rates: *TBD*

Number of Nodes: *TBD*

Bus architecture and interface for Nodes: *TBD*

Memory per Node: *TBD*

LAN/Ethernet 802.3 Requirements:

Number of Nodes: *TBD*

Transmission Media: *TBD*

Packet Transfer Rates: *TBD*

Other Network Requirements: *TBD*

### **Test Instrumentation Cart**

**Definition:** Each test cart contains a completely stand alone integrated data acquisition and control system.

**Requirements:** It is anticipated that the system will rely heavily on emerging VME, Futurebus, and VXI technology. A lower level control and data bus shall be provided so that various systems on the cart will have access to the same transducer inputs for control functions as well as test measurements where practical. Data shall be patched from the model to a patch panel for easy model setup and checkout. A fiber optics network link shall also be provided to the model for any on-board instrumentation. Signal conditioning shall be provided by this data system or, in some cases, by ancillary equipment for unique instrumentation. A higher level local area network (LAN) fiber optics communications bus connects the various processors on the cart to allow exchange of processed information. The static DAS, the dynamic DAS, and model attitude control systems shall remain as permanent systems on the cart, but additional systems to provide model engine simulator or high pressure air control, model surface control, probe control, or

acoustic dynamic data acquisition can be installed as required. When these systems are added to the cart, they shall be connected to the data bus and inter-processor LAN communications bus which allows them to be integrated and controlled by software. Workstations and X terminals connect to the LAN to support the cart in the model build-up bay area. All calibration, model attitude, model engine simulator or high pressure air operation, model surface movement, hook-up and checkout can be accomplished with the data and control systems on the cart; however, a fiber optics network shall connect the cart to either data analysis room for customer checkout before moving the cart to the tunnel. Power shall be maintained on the cart during movement to the test section to maintain constant cooling to the analog equipment so as not to affect calibration coefficients or require a prolonged warm-up period.

### Criteria:

#### Cart Network Subsystems:

Standards: appropriate federal open systems standards that are applicable to networks - *TBD*

#### Reflective Memory Network Subsystem:

Transmission Media: *TBD*

Transfer Rates: *TBD*

Number of Nodes: *TBD*

Bus Architecture and Interface for Nodes: *TBD*

Memory per Node: *TBD*

LAN/Ethernet 802.3 Requirements:

Number of Nodes: *TBD*

Transmission Media: *TBD*

Packet Transfer Rates: *TBD*

Other Network Requirements: *TBD*

Refer to each cart subsystem below for the appropriate criteria for that category of equipment.

### **Test Static Data System**

**Definition:** The test static data system acquires data from the test model, the model support systems, and other areas adjacent to the test section.

**Requirements:** Full software support is required for signal conditioning, system calibration, system diagnostics, conversion of data to engineering units and coefficients, and driving of real-time display systems for the technicians during model set-up and calibration. Appropriate data shall also pass to the on-cart model attitude control system for command and control of the model attitude, model engine simulators, and model surfaces. This system shall also synchronize and control the electronic pressure scanning system for acquiring up to 2000 ports of pressure data. Up to 256 channels of analog data shall be acquired and 24 channels of digital information. Digital information shall include binary, BCD, Datex code, resolver inputs, and special instruments requiring RS 232 or IEEE 488 protocol. When the cart is moved to the test section, a

single X terminal shall be used to perform any required diagnostics through the data processor for final checkout. The cart shall then be connected by a fiber optics LAN to the central control room where command and control will be conducted during the test.

Criteria:

Data Acquisition Unit:

Size and Packaging: *TBD*  
Power Requirements: *TBD*  
Cooling Requirements: *TBD*

Active Filters:

Up to 4 programmable selections per channel - selections: *TBD*  
Filter Characteristics: 4 pole Butterworth or Bessel *TBD*

Signal Conditioning:

Channel Count Requirements: *TBD*  
Variable Transducer Supply Excitation Voltage Range: *TBD*  
Bridge Completion Characteristics: *TBD*  
Auto Zero Capability: *TBD*  
Modes supported: strain gage, thermocouple, RTD

Amplifier characteristics:

Amplifier Per Channel  
Input Impedance: greater than 10 megohm  
Common Mode rejection: 120 db minimum  
Gain Ranges: 12 minimum, covering 5 mv. up to 10 volt, FS

Additional Features:

Programmable Sampling Rate: *TBD*  
Automatic Calibration Capability: *TBD*  
Overall System Accuracy and Noise: *TBD*

Computer Subsystem:

Size and Packaging: *TBD*  
Power Requirements: *TBD*  
Cooling Requirements: *TBD*  
Standards: appropriate federal open systems standards *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. *TBD*  
Bus Architecture: *TBD*

Revision C**Peripherals:**

Fixed Disk: Size, transfer rate, format *TBD*  
Removable Disk: Size, transfer rate, format *TBD*  
Optical Disk: Size, transfer rate, format *TBD*  
Archive Tape: Size, transfer rate, format *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF,  
meeting appropriate standards for networking, portability,  
and other features - *TBD*

Custom designed data acquisition, calibration, control, and real-time display software  
appropriate for meeting the acquisition and display requirements noted above - *TBD*

**Dynamic Pressure Data System**

**Definition:** The dynamic pressure data system will acquire data from the dynamic pressure instrumentation.

**Requirements:** Up to 80 channels of dynamic pressure data shall be acquired. It is anticipated that this system will have an analog to digital converter per channel with up to 10 megabytes of buffer ram per channel. Data shall be dumped to high speed 20 Gigabyte removable disks for archiving. The control processor shall support a graphical signal analysis package with the cart and shall be controlled from the central control room during tunnel testing. Each channel shall have programmable gain and filter setting with appropriate signal conditioning for the transducers. The system shall acquire data at up to 100 KHz per channel.

**Criteria:****Data Acquisition Unit:**

Size and Packaging: *TBD*  
Power Requirements: *TBD*  
Cooling Requirements: *TBD*

**Active Filters:**

Up to 4 programmable selections per channel selections: *TBD*  
Filter Characteristics: *TBD*

**Signal Conditioning:**

Channel Count Requirements: *TBD*  
Variable Transducer Supply Excitation Voltage Range: *TBD*  
Bridge Completion Characteristics: *TBD*  
Modes supported: strain gage, thermocouple, RTD

**Amplifier characteristics:**

Amplifier Per Channel  
Input Impedance: greater than 10 megohm  
Common Mode rejection: 120 db minimum  
Gain Ranges: 12 minimum, covering 5 mv. up to 10 volt, FS  
Auto Zero Capability: *TBD*

**Additional Features:**

Programmable Sampling Rate: *TBD*  
Buffer Memory Size Per Channel: *TBD*  
Automatic Calibration Capability: *TBD*  
Overall System Accuracy and Noise: *TBD*

**Computer Subsystem:**

Size and Packaging: *TBD*  
Power Requirements: *TBD*  
Cooling Requirements: *TBD*  
Standards: appropriate federal open systems standards *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE, SCSI, RS 232, FDDI, etc. - *TBD*  
Bus Architecture: *TBD*

**Peripherals:**

Fixed Disk: Size, transfer rate, format *TBD*  
Removable Disk: Size, transfer rate, format *TBD*  
Optical Disk: Size, transfer rate, format *TBD*  
Archive Tape: Size, transfer rate, format *TBD*  
Hard Copy Units: *TBD*  
X Terminal Characteristics: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF,  
meeting appropriate standards for networking, portability,  
and other features - *TBD*

Custom designed data acquisition, calibration, control, and real-time display software appropriate for meeting the acquisition and display requirements noted above - *TBD*

### Hot Wire Anemometer Data System

**Definition:** This system will record data from special signal conditioners utilizing constant temperature and constant current controllers for hot wire and hot film sensors. In addition, 24 channel of microphone data will also be provided. This system is used to measure hot wire and hot film anemometer instrumentation mounted directly on the model or in the tunnel air flow areas.

**Requirements:** One complete hot wire anemometer data system shall be provided for each cart. The system shall include the following components:

- Sensors
- Surface Mounted Hot Film Anemometer CTA System
- Hot wire/Film Probe Anemometer CTA/CCA System
- Signal Conditioner AC/DC Splitter
- Static DAS (for reading DC component)
- Transient Data Recorder (TDR) DAS 100 Khz
- Transient Data Recorder (TDR) DAS 1.25 Mhz
- Anemometer DAS CPU
- Anemometer DAS Workstation

**Sensors** - Two types of sensors shall be provided: the constant temperature anemometer (CTA) and the constant current anemometer (CCA) hot wire probes and hot film. In addition, 24 microphones shall be employed to acquire acoustic data at rates up to 100 Khz.

**Surface Mounted Hot Film Anemometer CTA System** - The sensing units shall be powered and signal conditioned by a multi-channel anemometer system which provides computer control of calibration, gain, offset, and filtering. The output signal bandwidth shall be DC to 40 Khz and the output amplitude shall be 5 to 15 VDC and 1 to 750 Mv AC.

**Signal Conditioner AC/DC Splitter** - The analog output signals from the anemometer system shall be input to the signal conditioner units. These multi-channel units are required to buffer the incoming signal to two outputs. One output shall be AC coupled and one output shall be DC coupled. The AC coupled output amplifier shall block the DC signal component and provide selectable gain to drive the maximum of 10.24 volts into the TDR. The DC coupled output amplifier shall provide both gain and attenuation settings to drive or limit the maximum signal of 10.24 volts into the Static DAS.

**Anemometer Static DAS** - The Static DAS system shall consist of 80 channels of voltage inputs from the signal conditioner AC/DC splitter units. The Static DAS shall have a programmable low pass filter and auto-ranging gain capability. The selectable filters shall filter out the AC component of the anemometer signal. The channels, gains, and filter selection shall all be contained in a scan table that resides in the DAS unit. The scan rate shall also be programmable. The unit shall provide self calibration and correction capability.

**Transient Data recorder (TDR) Das 100 Khz** - The TDR shall provide high speed sampling and recording of multiple analog inputs at data rates up to 250 Khz. Sampled data shall be stored in 10 MB of on-board DRAM for each analog channel. The data shall be off loaded between runs through a high speed data bus and to disk. The unit shall feature a 16 bit analog to digital converter with input gain and low pass filtering. Unit calibration is required, using an external voltage calibration standard. Software and hardware features support system calibration. Several methods of triggering shall be available, including program control, external logic signal, and analog level detection on one channel. Twenty four additional channels shall be provided to acquire microphone data.

**Transient Data Recorder (TDR) DAS 1.25 Mhz** - The TDR shall provide high speed sampling and recording of multiple analog inputs at data rates up to 1.25 Mhz. Sampled data shall be stored in 10 MB of on-board DRAM for each analog channel. The data are required to be off loaded between runs through a high speed data bus and to disk. The unit shall feature a 16 bit analog to digital converter with input gain and low pass filtering control. Unit calibration shall be accomplished using an external voltage calibration standard. Software and hardware features support system calibration. Several methods of triggering shall be available, including program control, external logic signal, and analog level detection on one channel.

**Anemometer DAS CPU** - The Anemometer DAS CPU shall act as the host for controlling the data acquisition with the Anemometer Static DAS, the TDR 100 Khz and the TDR 1.25 Mhz. The calibration calculations and engineering units conversion shall also take place in the DAS CPU. The DAS CPU shall put the converted data out on the local area network as well as storing it on a local hard disk. A graphical user interface package shall be provided to control the acquisition process.

**Anemometer DAS Workstation** - The DAS workstation is required to act as the operator interface for the entire anemometer system. The local area network shall provide the link between the anemometer DAS CPU and the workstation. The programming and scan list creation, scan initialization, synchronization and semi-real time graphical display of the resultant data shall all be functions of the workstation. Software to run FFT's and perform other signal analysis on the data shall also be available. The operator interface software shall be a standard Windows compatible off the shelf package with enhancements.

**Criteria:****Surface Mounted Hot Film Anemometer CTA System:**

Size and Packaging: *TBD*  
Power Requirements: *TBD*  
Cooling Requirements: *TBD*  
Channel Count Requirements: 64 channels per cart  
Type Bridge: Non Linear, Constant Temperature type  
Bridge Ratios: 1:10, 1:1  
Sensor Resistance Range: 1:10 - 1-9.9 Ohms, 1:10 - 1.5-99 Ohms  
Signal Conditioner Output Voltage: +/- 12V  
Gain Accuracy: +/- 0.2%  
Frequency Range: DC - 40 KHz

**Hot Wire/Film Probe Anemometer CTA/CCA System:**

Channel Count Requirements: 16 channels per cart  
Type Bridge: Constant Current type  
Signal Conditioner Output Voltage: +/- 12V  
Accuracy: +/- 0.5%  
Frequency Range: DC - 500 KHz

**Signal Conditioner AC/DC Splitter:**

Channel Count Requirements: 80 channels per cart  
Selectable gain steps: *TBD*  
Frequency Response: DC - 500 KHz

Two Buffered Outputs per Input:  
Output 1: DC Coupled, +/- 12V  
Output 2: AC Coupled, +/- 12V

Linearity: 0.005% of full scale

**Static DAS:**

Active Filters:  
Up to four programmable selections per channel; 1 Hz, 10 Hz, 100 Hz, 1000 Hz.

Filter Characteristics:  
4 pole Butterworth or Bessel - *TBD*

**Amplifier Characteristics:**

Amplifier Per Channel

Input Impedance: Greater than 10 Megaohm

CMR: 120 dB minimum

Gain Ranges: 12 minimum, 5 mV up to 10.24V FS

**Additional Features:**Programmable Sample Rate: *TBD*Automatic Calibration Capability: *TBD*Overall System and Noise: *TBD***Transient Data Recorder DAS 100 KHz:**

Sample Rate: Programmable, 100 KHz minimum

**Amplifier Characteristics:**Programmable Gain: *TBD*Programmable Filter: *TBD*

A/D Resolution: 14 Bits

Buffer Memory: 10 MB

Trigger Modes: Programmable, external, level detection

Accuracy: *TBD*Phase Coherency: *TBD*Calibration: *TBD*

Interface: High Speed DMA style, 2 MB/sec transfer rate

**Transient Data Recorder DAS 1.25 MHz:**

Sample Rate: Programmable, 1.25 MHz minimum

**Amplifier Characteristics:**Programmable Gain: *TBD*Programmable Filter: *TBD*

A/D Resolution: 12 Bits

Buffer Memory: 10 MB

Trigger Modes: Programmable, external, level detection

Accuracy: *TBD*Phase Coherency: *TBD*Calibration: *TBD*

Interface: High Speed DMA style, 2 MB/sec transfer rate

**Anemometer DAS CPU:**

Standards: Appropriate federal open systems standards *TBD*  
Clock Rate: *TBD*  
Processing Speed: *TBD*  
Memory Cycle Time: *TBD*  
Memory Size: *TBD*  
Interfaces Supported: IEEE-488, SCSI, RS 232, FDDI, etc. *TBD*  
Bus Architecture: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Anemometer DAS Workstation:**

Processor Type (RISC, CISC): *TBD*  
Clock Speed: *TBD*  
Memory: *TBD*  
Disk Capacity: *TBD*  
Data Interchange/Software Distribution Media: *TBD*  
Graphics Capability: *TBD*  
Archive Capability/Media: *TBD*  
Expansion Slots: (S-Bus, VME, etc.) - *TBD*  
Cache Size: *TBD*  
Network Interfaces and Packet Transfer Rates: *TBD*

**Software:**

Real-time Posix Operating System with X Window/MOTIF, meeting appropriate standards for networking, portability, and other features - *TBD*

Custom designed data acquisition, control, and real-time display software appropriate for meeting the acquisition and display requirements noted above - *TBD*

Data Analysis Software Tools - Software for signal processing, visualization, data reduction, database management, and other features typically required for data analysis.  
Final Requirements - *TBD*

**Acoustic Data System**

**Definition:** A modular high speed dynamic data system provides a system for acquiring acoustic data.

**Requirements:** The system shall be made up of modules containing about 16 channels of A/D, memory, filters, a CPU and a disk drive. The total system shall be made up of enough modules to acquire 256 channels of data. Although most of the A/D channels will be capable of data sampling up to 50,000 samples/sec, one module (16 channels) shall be capable of acquiring data at 250,000 samples/sec. The system modules can be assembled to meet specific test objectives, such as a low speed test where many channels would be required, or a high speed test with fewer

sensors but high data sampling rate requirements. In conjunction with the acoustic data acquisition system, a collection of microphones, pre amplification equipment, cables, and calibration equipment shall be provided

Criteria:

Microphones: **TBD**

Signal Conditioning:

Number of Channels: 256

Pre-amp Gain Steps: **TBD**

Calibration Capability: **TBD**

Frequency Range: **TBD**

Output Voltage: **TBD**

Excitation Supply: **TBD**

Bridge Completion: **TBD**

A/D Modules:

Number of Channels: 256

Programmable Gain Steps: **TBD**

Programmable Filter Steps: **TBD**

Sample Rate (All Channels Scanned): 50 KHz

Sample Rate (16 Channels): 250,000 KHz

Memory: **TBD**

Interface: High Speed DMA type, 2 MB/sec transfer rate

Acoustic DAS Computer subsystem:

Standards: Appropriate federal open systems standards - **TBD**

Clock Rate: **TBD**

Processing Speed: **TBD**

Memory Cycle Time: **TBD**

Memory Size: **TBD**

Interfaces Supported: IEEE-488, SCSI, RS 232, FDDI, etc. - **TBD**

Bus Architecture: **TBD**

Network Interfaces and Packet Transfer Rates: **TBD**

Disk Capacity: **TBD**

Software:

Real-time Posix Operating System with X Window/MOTIF, meeting appropriate standards for networking, portability, and other features - **TBD**

Custom designed data acquisition, control, and real-time display software appropriate for meeting the acquisition and display requirements noted above - **TBD**

Data Analysis Software Tools - Software for signal processing, visualization, data reduction, database management, and other features typically required for data analysis.

Final Requirements - *TBD*

#### 1.5.5.4 Instrumentation

**Definition:** Overall instrumentation system of the Transonic Speed Wind Tunnel (TSWT) Complex includes four major instrumentation components and an additional one that integrates the entire instruments and their associated components. These five components are: Test Instrumentation, Calibration Instrumentation, Acoustics Instrumentation, Process Instrumentation, and Hardware Integration.

Test instrumentation is a stand-alone instrument system that is intended to acquire fluid dynamic parameters required of wind tunnel experiments of a given model in the test section of the tunnel. The test instrumentation system is an integral part of the four test section carts, and links to various computers and workstations of the tunnel complex through a high speed control and data bus of the tunnel data acquisition and control system. These carts are the test section internal components, consisting of movable walls, model support systems, and model support structures. The test section cart is placed and transported in a movable plenum cart which translates in and out of the tunnel circuit on a rail.

Calibration instrumentation systems are intended for tunnel calibrations as well as for tunnel shakedown operations. Information obtained by the calibration instrument systems are made available to the computers and workstations of the TSWT Complex through the high speed control and data bus. Acoustic instrumentation systems are used to obtain acoustic properties of open jet configurations, such as acoustic rake survey data and effectiveness of the acoustic enclosure/treatment. Process instrumentation systems monitor various tunnel parameters, with specific emphasis on those related to the flow quality and tunnel safety, which are fed back to the tunnel control devices.

Hardware integration of the above four components of instrumentation system are required to interconnect the various instruments and systems to function in a manner prescribed by the experimental and safety requirements.

#### **Requirements:**

**Test Instrumentation:** There shall be four test instrumentation systems for the four test section carts. These four carts shall be fully assembled with the test instrumentation system and operate independently. The test instrumentation systems shall measure aerodynamic and related parameters including: force, skin-friction, static and dynamic pressure, acceleration, displacement, rotation, acoustic, and temperature. In addition, the test instrumentation systems shall have self-contained optical capabilities of making measurements of model deformation, angle-of-attack, flow visualization, and high speed video surveillance.

**Calibration Instrumentation:** The calibration instrumentation systems shall provide pressure data for center-line, rotary rakes, circuit, fluctuating wall, and compressor. The calibration

instrumentation shall also provide data on: vibration, rotary rake total temperatures, boundary layer rakes, and strain of the tunnel structures.

**Acoustic Instrumentation:** The baseline requirement for acoustic measurements shall be for obtaining acoustic information about open jet traverse and test section. In addition, the system shall provide acoustic data for tunnel baseline calibration.

**Process Instrumentation:** The instrumentation systems for tunnel processing shall provide data for Mach numbers, pressures and temperatures for the cooler system, a series of pressures, temperatures, vibrations, positions, and angles for the tunnel compressor. Process instrumentation systems shall also furnish information for the following parameters: test section wall positions, tunnel circuit dew points, motor power/voltage, water flow, high pressure compressor, dryer, vacuum pump, vacuum storage tank, cool tower, heat exchanger, choke finger positions, and nozzle jack positions.

**Hardware Integration:** The test section cart includes the test section floor model support systems and attached instrument housing. The pressure connections for all test instrumentation shall penetrate the instrument housing wall that will make up part of the pressure vessel when installed in the tunnel. Wires attached to instrumentation inside the model or sting shall exit through the test section floor and then shall exit the tunnel through the instrument housing pressure wall. A production oriented facility requires the complete test section (not just the floor) to be made available in the model preparation bays for set-up, alignment, and equipment warm-up and stabilization. Permanent connections mounted on one wall of the main test section plenum near the area that the test cart instrument housing would reside shall be provided. Optical instruments shall be patched into the instrument housing after the cart assembly is in place and ready for a test run. The process instrumentation wiring shall be designed to provide flexibility during normal testing and also provide tunnel calibration facilities when used in conjunction with one of the test section carts. One ESP system (two counting the cart system) shall make up the majority of pressure measurements. The Mach Number System shall include two completely independent measuring systems for redundancy. The three uniform temperature references (UTR) shall be provided and have the ability to provide cold junction compensation for any type of thermocouple and can also be used for any analog signal input to the data systems. The strain gage junction boxes shall provide power, sense, re-calibration, and signal conditioning for discrete bridge type instrumentation. These junction boxes can also be used to input other analog signals into the data system.

**Criteria:**

**Test Instrumentation:**

Pressure Measurements	
Test Section (Static) - 400 channels	<i>TBD</i>
Model Module (Static) - 2000 channels	<i>TBD</i>
Dynamic Pressures - 80 channels	<i>TBD</i>
Temperature Measurements	
T/C and RTD - 24 channels	<i>TBD</i>
Angle Of Attack	
Inertial System - 3 channels	<i>TBD</i>
Optical System	<i>TBD</i>
Vibration - 4 channels	<i>TBD</i>
Component Position System	<i>TBD</i>
High Speed Video System	
Surveillance and Safety - 6 channels	<i>TBD</i>
Structural/Model Vibration - 6 channels	<i>TBD</i>
Model Deformation Systems	<i>TBD</i>
Vapor Screen	<i>TBD</i>
Skin Friction Balance System	<i>TBD</i>
Anemometer System	<i>TBD</i>
Flow Visualization	
Laser Light Sheet	<i>TBD</i>
Tufts and Oil Flow	<i>TBD</i>

**Calibration Instrumentation:**

Center Line Probes	
Static Pressures - 300 channels	<i>TBD</i>
Acceleration - 2 channels	<i>TBD</i>
Rotary Rake	
Flow Angle	<i>TBD</i>
Temperatures (Ref. to Test Instrumentation)	
Pressures (Ref. to Test Instrumentation)	
Turbulence (Ref. to Test Instrumentation)	
Circuit Static Pressures (Ref. to Test Instrumentation)	
Fluctuating Pressures - 10 channels	<i>TBD</i>

**Acoustic Instrumentation:**

0.25 inch Microphone Systems - 24 channels	<i>TBD</i>
0.5 inch Microphone Systems - 24 channels	<i>TBD</i>
5 Hz to 40 KHz bandwidth	
96 dB Dynamic Range	
Max. Sound Pressure Level :164 dBs	

**Process Instrumentation:*****TBD***

Mach Number Systems  
 Cooler (Pressures and Temperatures)  
 Compressor System  
     Inlet and Outlet Pressures  
     Inlet and Outlet Temperatures  
     Oil Pressures and Temperatures  
     Vibration  
     Eddy Current Probes  
     RPM and Position  
     Angles (Roll, Pitch, Turntable)  
 Test Section Wall Position  
 Dew Points  
 Motor Power/Voltage  
 Water Flow  
 Air Nozzle Instrumentation  
 High Pressure Compressor System  
 Dryer  
 High Pressure Air Storage and Heater  
 Vacuum Pump System  
 Cool Tower  
 Heat Exchanger  
 Valve Positions

**Hardware Integration:**

Test Cart Wiring	<b><i>TBD</i></b>
Optical System	<b><i>TBD</i></b>
Process Instrumentation Wiring	<b><i>TBD</i></b>

**1.5.5.5 Predictive Maintenance System**

**Definition:** The predictive maintenance system includes all the electrical/electronic components, cabling, and software required to monitor the health of the TSWT, provide indications for nonscheduled maintenance, and predict normal maintenance schedules for components/subsystems. This WBS does not include sensors.

**Requirements:** The predictive maintenance system shall acquire data at a rate and accuracy to ensure readiness of TSWT to operate. The system shall utilize redundant sensors where necessary to minimize nuisance trips due to errors in individual sensors and system noise. Advanced on-line AI techniques are needed to minimize maintenance requirements and rapidly identify and isolate problems in specific components when operational status is threatened. Communication is required between this system and the control systems for the tunnels and auxiliary systems.

**Criteria:**

- Standards: *TBD - Design*
- System Availability *TBD*
- Data Sample Rate *TBD*
- Data Accuracy *TBD*
- Solution Time for Failure Identification *TBD*
- Communication Rate for Control Systems *TBD*

**1.5.6 Activation****1.5.6.1 Integrated System Checkout**

**Definition:** The TSWT checkout is initiated when all of the system-level component checks have been completed and any significant deficiencies, identified in the process, have been corrected. An Integrated Systems Review (ISR) will be conducted to validate readiness prior to initiation of the integrated system testing of the TSWT facility.

**Requirements:** The integrated system testing matrix shall include operation of the facility to the boundaries of the performance envelope to determine/document the safe limits of the facility operation. A tiered approach to integration of the system testing requirements shall be utilized to ensure equipment/personnel safety during checkout. A comprehensive checkout plan which describes the required elements of TSWT integrated system testing shall be prepared as part of this work element.

**Criteria:** *TBD*

**1.5.6.2 Tunnel Calibration**

**Definition:** Validation/calibration of the TSWT facility includes the activities associated with the measurement of the test section flow parameters over the range of facility test conditions to (1) validate compliance to requirements (flow quality, performance, etc.) and (2) provide a basis for the development of the test section calibration.

**Requirements:** This work element includes all labor, materials and utilities required to conduct the TSWT validation/calibration from planning through calibration. An Operational Readiness Review (ORR) is conducted prior to the initiation of validation/calibration testing in the facility. The ORR provides a comprehensive assessment of the facility, equipment, procedures, staffing and overall readiness for initiation of validation/calibration testing.

**Criteria:** *TBD*

### **1.5.6.3 Provisioning**

**Definition:** This work element provides all of the equipment required to maintain the productivity of the TSWT facility during normal operations. The equipment will include all of the routinely replaced parts which can fail and must be available for rapid replacement.

**Requirements:** *TBD*

**Criteria:** *TBD*

## **APPENDIX A REFERENCE DOCUMENTS**

### **Appendix A.1 Model Design Criteria and Facility Users Manual**

**Definition:** The Model Design Criteria and Facility Users Manual is a stand alone document between the facility and users, who build the models. It is the first document that a potential user encounters in becoming acquainted with the facility. This document not only describes the minimum criteria for model acceptance from a safety viewpoint, but also productivity requirements and interface documents for physical, electrical and data connections.

**Requirements:** The Model Design Criteria and Facility Users Manual shall be written as a facility user's guide to be used by new users and model contractors alike. This document will encompass the following areas:

- (1) Facility Users Guide
  - Introduction to Facility/Description/Capabilities
  - Description of Unique, Calibration Capabilities
  - Milestones/Timeline of a Model Test
  - Mechanical/Electrical Interfaces
- (2) Productivity Requirements
  - Instrumentation and Control Requirements
  - Model Change Times
- (3) Safety
  - Risk Definition
  - Design Requirements

## **Appendix A.2 System Engineering Plan**

**Definition:** The System Engineering Plan is a document which contains management information and a comprehensive set of rules, guidelines, and procedures to be used during the execution of the design, construction, and activation phases of the NWTC. Its purpose is to assure that the wind tunnels are designed and constructed to the required standards and meet the performance requirements.

**Requirements:** The System Engineering Plan shall provide a framework for the NWTC acquisition, technical management, and design integration. Major components of this plan are:

- (1) The identification of the technical high risk areas.
- (2) Specific documentation of the interface definitions for related systems, subsystems, and components.
- (3) The documentation, control, and maintenance of all functional and physical requirements and specifications throughout the acquisition process.
- (4) The establishment of a comprehensive systematic process for the management of items 1-3 and the relationship of the information flow from this process to the related project management functions.
- (5) The development of a knowledge based system of information, which will underpin the system engineering process for the full productive life of the NWTC.

### **Appendix A.3 General Facility Operating Plan**

Definition: Later

Requirements: Later

**Appendix A.4 Baseline Test Program****LSWT Baseline Test Program**

Test Objective: Optimum configuraion development; transport configuration; takeoff/landing outside ground effects

Mount: Turntable and tripod struts

Instrumentation: External balance, 300 pressures

Mach # Schedule: A: 0.20, 0.25 (2 runs)

Pitch Angle Schedule: A: 0, -6, -4, -2, 0, 2, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16,  
18, 20, 22, 24, 26, 28, 30, 0 (25 points)  
B: 0, -4, 0, 4, 6, 8, 10, 12, 16, 0 (10 points)

Yaw Angle Data: Obtained at +5 and +10 on every configuration

**Table A.4.a LSWT Test Plan**

Config.	P <sub>t</sub> , psia	Mach #	Pitch	Yaw	Roll	Runs (Polars)	Cum. Points
Baseline	9	A	B	0	0	1-2	1-20
Baseline	9	A	B	+5	0	3-4	21-40
Baseline	9	A	B	+10	0	5-6	41-60
Baseline	15	Same As Runs 1-6	Same As Runs 1-6	Same As Runs 1-6	Same As Runs 1-6	7-12	61-120
Baseline	37	Same As Runs 1-6	Same As Runs 1-6	Same As Runs 1-6	Same As Runs 1-6	13-18	121-180
Baseline	60	Same As Runs 1-6	Same As Runs 1-6	Same As Runs 1-6	Same As Runs 1-6	19-24	181-240
Baseline	75	Same As Runs 1-6	Same As Runs 1-6	Same As Runs 1-6	Same As Runs 1-6	25-30	241-300
Config. 1	75	A	A	0	0	31-32	301-350
Config. 1	75	A	B	+5	0	33-34	351-370
Config. 1	75	A	B	+10	0	35-36	371-390
Config. 1	60	A	A	0	0	37-38	391-440
Config. 2-150	Same As Runs 31-38	Same As Runs 31-38	Same As Runs 31-38	Same As Runs 31-38	Same As Runs 31-38	39-1,230	441-21,300
Config. 151	Same As Baseline	Same As Baseline	Same As Baseline	Same As Baseline	Same As Baseline	1,231-1,260	21,301-21,600
Config. 152	Same As Baseline	Same As Baseline	Same As Baseline	Same As Baseline	Same As Baseline	1,261-1,290	21,601-21,900

**TSWT Baseline Test Program**

**Test Objective:** Optimum configuraion development; high supsonic cruise

**Mount:** Pitch strut

**Instrumentation:** Internal balance, 300 pressures

**Mach # Schedule:** A: 0.5, 0.7, 0.8, 0.825, 0.85, 0.9, 0.95 (7 runs)

**Pitch Angle Schedule:** A: 0, -10, -8, -6, -4, -2, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20, 22, 0 (25 Points)  
B: 0, -4, -3, -2, -1, 0, 1, 2, 3, 4, 0 (11 Points)  
C: 0, 4, 8, 12 (4 Points)

**Yaw Angle Data:** Obtained at +5 and +10 on baseline and every 10 configurations

**Table A.4 b TSWT Test Plan**

Config.	P <sub>t</sub> , psia	Mach #	Pitch	Yaw	Roll	Runs (Polars)	Cum. Points
Baseline	9	A	B	0	0	1-7	1-77
Baseline	9	A	B	0	180	8-14	78-154
Baseline	9	A	A	0	0	15-21	155-329
Baseline	9	A	C	+5	0	22-28	330-357
Baseline	9	A	C	+10	0	29-35	358-385
Baseline	15	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	36-70	386-770
Baseline	37	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	71- 105	771- 1,155
Baseline	60	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	106- 140	1,156- 1,540
Baseline	75	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	Same As Runs 1-35	141- 175	1,541- 1,925
Config. 1	60	A	A	0	0	176- 182	1,926- 2,100
Config. 2-9	60	Same As Runs 176-182	Same As Runs 176-182	Same As Runs 176-182	Same As Runs 176-182	183- 238	2,101- 3,500
Config. 10	60	A	A	0	0	239- 245	3,501 3,675
Config. 10	60	A	C	+5	0	246- 252	3,676- 3,703
Config. 10	60	A	C	+10	0	253- 259	3,704 3,731
Config. 11-80	Same As Runs 239-259	Same As Runs 239-259	Same As Runs 239-259	Same As Runs 239-259	Same As Runs 239-259	260- 1,729	3,732- 19,901
Config. 81	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	1,730- 1,890	19,902- 21,672
Config. 82	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	Same As Runs 15-175	1,891- 2,051	21,673- 23,443

**Appendix A.5 Safety, Reliability, and Quality Assurance Plan**

**Definition:** The Safety, Reliability and Quality Assurance Plan is a comprehensive document, which describes the planned approach to insure that a quality facility is designed and built, meeting all requirements. Items are included covering the project, from start to finish.

**Requirements:** This document shall contain information, guidelines, procedures, and plans for the following items:

**(1) Design**

Design Criteria and Standards  
Design Review Process  
Design Approval Process  
Configuration Management Control System

**(2) Construction**

Listing of Applicable Codes  
Nondestructive Examination Plans  
Shop Testing Procedures  
Site Testing Procedures

**(3) Activation and Calibration**

Shakedown Test Procedures  
Calibration Test Procedures

**(4) Documentation**

Operating and Maintenance Procedures  
Safety Analysis Report

**ATTACHMENT 6**

**NATIONAL WIND TUNNEL COMPLEX**

**DESCRIPTION OF AREAS OF STUDY**



## DESCRIPTION OF AREAS OF STUDY

### Concept Baseline Development and Assessment

#### **Study Number 1.7.1.1.1 Aerodynamic Lines and Loads Study**

**Background and Purpose:** The National Wind Tunnel Complex (NWTC) is an integrated test complex. The fundamental objective of the NWTC is to provide wind tunnels which are responsive to customer needs in support of aircraft development. The NWTC will provide highly productive aerodynamic and acoustic test facilities. The purpose of the NWTC is to provide testing facilities that provide adequate Reynolds number capability for aircraft developmental testing, high productivity and reliability, superior data quality, and low cost per data point. The NWTC will provide the capability for aeronautical, propulsion simulation, and acoustical developmental testing in the subsonic and transonic speed regimes.

The initial aspect for any wind tunnel design is to determine an efficient circuit layout. This includes internal component sizing and arrangement, definition of the total performance envelope for the tunnel as well as the required performance for all of the internal components. Definition of the required performance of the associated auxiliary process systems and facility infrastructure is another aspect that needs to be considered. The issues surrounding the operating cost, the productivity, and the acoustic aspects of this complex will require an extremely efficient aerodynamic circuit. In order to achieve the requirements, developing a systematic optimum design is necessary.

**TASK DESCRIPTION:** The scope of this task is to develop a baseline aerodynamic configuration for the LSWT and the TSWT, develop baseline aerodynamic loads; and to determine derived performance requirements for the primary tunnel internal components, auxiliary process systems, buildings, and the site and infrastructure that are fundamental to the operation of the tunnels. The focus of the study is to define a baseline aerodynamic configuration of the two tunnels and to optimize their performance.

The baseline configuration includes development of the aerodynamic lines for the LSWT and the TSWT, determination of the base loads on the pressure shell and tunnel internal components due to static and dynamic aerodynamic loadings as well as thermal effects, development of concepts for all tunnel internal components as well as the pressure shell, determination of the primary derived performance requirements for the tunnel internal components and, the auxiliary process systems. The baseline configurations shall be optimized to ensure the performance requirements are met.

### **Study Number 1.7.1.1.3 TSWT Acoustic Test Section Concept Study**

**Background:** The acoustic test section for the TSWT will provide a unique opportunity to explore noise problems associated with propulsion systems. The test section will be a closed test section with all of the flow qualities of the 'regular' aerodynamic test sections with the added feature of acoustically absorbent walls. It is envisioned that the primary transducer locations will be flush mounted to the wall or model surfaces, so the noise floor for the test section will be set by the fluctuating pressure levels in the turbulent boundary layer. The in-flow noise coming into the test section from the remainder of the circuit will be much less than this, no greater than 95 dB at Mach = 0.8. Development risk for this test section requires a preliminary study to determine how much is known about this type of acoustic treatment and how much must be developed to meet the acoustic testing requirements.

**Purpose:** The purpose of this study is to produce a conceptual design for a closed wall acoustic test section that meets the acoustic testing requirements specified for the TSWT.

#### **Task Description:**

1. Analyze available data from existing and proposed closed acoustically treated test sections to determine how the acoustic requirements can be met using existing methods.
2. Define candidate concepts for the TSWT Acoustic Test Section Cart
3. Define a test program required to verify and/or develop the acoustic test section
4. Document results of the study.

### **Study Number 1.7.1.1.13 Cart / Test Section / Model Support Integration**

**Background:** The Plenum / Test Section Concept Study is an integral part of a study sequence which will conceptualize the NWTC prior to the Preliminary Engineering Report (PER) phase. The relationship of this study to the overall NWTC schedule execution is shown in Figure 1.1.

**Purpose:** The objective of this study is to select and develop a suitable concept for the integrated systems of model supports, test sections and moveable plenums for both the Low Speed Wind Tunnel (LSWT), and Transonic Speed Wind Tunnel (TSWT), of the National Wind Tunnel Complex (NWTC). Achievement of the high productivity requirements for these facilities hinges on the successful and reliable performance of these tunnel carting systems. This study will encompass most of the tunnel systems which have an impact on the NWTC throughput of testing capability, such that a true integration of these systems is expected to result. Although interchangeability of major components between the LSWT and the TSWT is not practical because of size mismatch, a commonality of the tunnel carting concepts is required.

**TASK DESCRIPTION:** The study is divided into three phases: (1) Requirements Review, (2) Concept Evaluation and Selection, and (3) Integrated System Concept Development.

**Phase 1: Requirements Review:**

Conduct a review of the plenum / test section study requirements, specifically addressing but not limited to, the following items:

- o Assessment of the compatibility of the performance / productivity requirements and design criteria for the plenum and test section components.
- o Identification of potential integration problem areas for the carting systems.
- o Identification of additional information needed to complete the study.
- o Review of study approach and identification of any recommendations for improvement of same.
- o Preliminary report of options to be evaluated in the Phase 1 portion of the study.

**Phase 2: Concept Evaluation and Selection:**

Conduct trade studies of candidate concepts for the LSWT and TSWT model support systems, test sections and rolling plenums. These trade studies should address, but not be limited to, the following items:

1. Aerodynamic performance expectations
2. Productivity performance expectations
3. Physical space requirements including airstream blockage
4. Complexity - integral vs. modular assemblies
5. Reliability and Maintainability
6. Commonality (LWST/TSWT)
7. Integration considerations
8. Rough-order-of-magnitude cost comparisons
9. Constructibility

Concepts are required for the following items:

- o Rear Strut Cart Assembly LSWT and TSWT
  - Rear Strut Model Support System
  - Rear Strut Test Section
  - Rear Strut Cart Drive System
- o Floor Mount Cart Assembly LSWT and TSWT
  - External Balance

- Floor Mount Model Support System
- Floor Mount Test Section
- Floor Mount Cart Drive System
- o Open Jet Cart Assembly LSWT only
  - Open Jet Model Support System
  - Open Jet Model Support Traversing System
  - Collector/Nozzle Lip Extension
  - Open Jet Microphone Traversing System
  - Open Jet Cart Drive System
- o Rolling Plenum Assembly LSWT and TSWT
  - Pressure Vessel
  - Internal Structure
  - External Balance Mount/Rails
  - Rolling Plenum Drive System

### **Phase 3: Integrated System Concept Development:**

The selected concepts will be further developed as integrated systems into the two facilities. All cart types and testing capabilities for both facilities will be considered. The following areas of concern will be specifically addressed in this phase:

1. Effective and reliable sealing of the rolling plenum pressure vessel.
2. Ease and controllability of moving the massive pieces of hardware involved.
3. Repeatable installation and alignment of the test section and rolling plenum.
4. Effective load path of model supports to ground (rigidity of model supports, especially for external balance tests.)
5. Test section installation in rolling plenum and rolling plenum installation in tunnel circuit within productivity time budgets. (Provide installation scenario)
6. Implementation of an automatic in-tunnel check loading system
7. Model support system positioning accuracy at the maximum loading condition.
8. Physical space requirements for mounting the external balance within the rolling plenum.
9. Integration of hot jet propulsion testing in the LSWT open jet test section.

### **Study Number 1.7.1.1.16 External Balance - Envelope & Load Path**

**Background:** The external balances are a crucial part of the test requirements, and will affect the design of the test carts. In fact, the entire tunnel design may well be affected, since the external balance design will be a contributor to the tunnel anchoring decision. These balances will measure very large loads to a high degree of accuracy, and must fit within a relatively small space envelope.

There are also two 6 component balances utilized in the airflow calibration laboratory that will be examined in this study.

Purpose: A feasibility study to examine balance envelope and attachment geometry to satisfy required accuracy and load requirements is required. This study will cover a series of 6 component external balances to be used in the National Wind Tunnel Complex wind tunnels and the airflow calibration lab.

TASK DESCRIPTION: A result of this activity will be the quantification of achievable accuracy and precision, and other operational/physical characteristics such as initial deflection constant predictions, diameters, recommended configurations, etc. Preliminary wiring diagrams, drawing layouts and stress calculations are also desired. Cost estimates shall be provided for each balance considered. Another area that shall be addressed is the balance calibration facilities required, and any special requirements that may be foreseen for calibration and maintenance of the balances.

***Study Number 1.7.1.1.7 and 1.7.1.1.8 TSWT and LSWT Fan Design Studies***

Background:

Purpose:

Task Description:

- a. ARC and AEDC will independently develop candidate designs.
- b. Jointly ARC and AEDC will review candidate designs and select baseline designs for each wind tunnel.
- c. ARC and AEDC will predict performance of the baseline designs and resolve and understand differences.
- d. LeRC will review baseline designs and then refine or replace the baseline designs as appropriate.
- e. Validate performance with model experiments; see items 7 through 23.
- f. Iterate d. and e. if required.

Goals

- a. Minimize noise (tip speed) while retaining good stall margin and high efficiency.
- b. Trade off tip speed and solidity.
- c. Predict stall margins and demonstrate conservatism.
- d. Large models with large blockages must be accommodated while still retaining good stall margin.
- e. Perform risk assessment considering uncertainties in circuit losses, model sizes, compressor performance, etc.

For the LSWT, trade off Mach Number with open jet and closed jet test sections.

Develop fan maps which include pressure loss, geometry, flow rate, rotational speed, power, etc.

#### **Study Number 1.7.1.1.9 Wall Interference Estimate Investigation**

**Background:** There are four parameters that determine Reynolds number in a wind tunnel facility, test medium, pressure, temperature, and size. Reynolds Number requirement for the National Wind Tunnel Complex are being satisfied by using air at ambient temperature, pressure up to 5-atm and test section sizes of 20x24 feet and 11 by 15.5 feet for the Low Speed and Transonic tunnels respectively. In order to achieve the projected maximum Reynolds number, model spans of up to 80% of the tunnel width will be needed. There is concern that, with models that large with respect to the tunnel dimensions, unavoidable wall and support interference will effect the usefulness of the test information produced. Preliminary calculations using classical theory indicate the data will not be correctable to free air conditions. One method of reducing the wall and support interference is by using the adaptive wall concept wherein the walls are adjusted at each condition to minimize the effect. However, such schemes are slow and will reduce productivity by factors of two or more. A more viable scheme is to use a passive wall configuration which will allow correctable data to be obtained. Information does not now exist which will allow such a wall to be designed. However, tools and techniques are available which will provide design information.

**Purpose:** To conduct a theoretical study to estimate the wall interference of the benchmark model configuration at the critical conditions specified below and, if deemed uncorrectable, provide candidate test section wall configurations for both the LSWT and TSWT that will yield data correctable by theoretical means over a wide range of model and test conditions.

#### **TASK DESCRIPTION:**

1. Using a full span benchmark model configuration (transport aircraft) and its support system and a floor mounted half span version of the same model configuration, estimate the effect of tunnel wall induced velocity/pressure perturbations on the quality of aerodynamic data; specifically, the effect on normal and axial force distributions over the model and the integrated effect on the aerodynamic force/moment coefficients. Of particular interest is the effect of the wall induced perturbations on the separation characteristics of the wing.

**Benchmark Model:** Transport configuration with the following characteristics -  
Wing Aspect Ratio: 10  
Full Scale Span: 200-feet  
Full Scale Fuselage Length: 200-ft  
Full Scale Fuselage Diameter: 20-ft

Four 133-in diameter engines with sea level mass flow of  
3200 lbs/sec  
Model Span to Tunnel Width Ratio: 0.8

Specific model geometry coordinates will be supplied by the McDonnell Douglas Company.

**Benchmark Test Conditions:**

LSWT - Mach number 0.3, total pressure 5-atm, lift coefficient 3.2

TSWT - Mach number 0.85, total pressure 5-atm, lift coefficient 0.5

**Benchmark Wall Configuration:** Eight Ames 11-ft baffled slots evenly distributed in each test section wall.

The method used to estimate the wall interference must have the capability to solve the Navier-Stokes equations in the vicinity of the model coupled with a turbulence model and appropriate model detail to reasonably represent the model separation characteristics. The wall interference distribution on the model surface shall be obtained by subtracting a solution in the tunnel from a free air solution using identical model grids. The wall boundary conditions shall be flexible in order to represent various slotted wall cross-flow properties as a function of local pressure and wall boundary layer conditions (Task 2). The wall cross-flow representation will be obtained from sources outside of this study. The upstream boundary conditions may be assumed uniform. Because there is a coupling between the model and the model support system blockage, that portion of the support system within the test section must also be included in the calculation.

2. If the calculations in Task 1 yield interference distributions which in the opinion of the Government will not allow data to be corrected, additional calculations shall be made with various wall cross flow property-distributions to suggest ventilated wall configurations which will produce correctable data over a wide range (Mach and Reynolds number) of tunnel operating conditions. This task shall also devise means to translate desired wall cross flow properties into geometric dimensions from which the experimental walls can be built. In order to do the trade studies in a timely manner, the capability shall be provided to obtain inviscid solutions. The promising wall configurations will be used in an experimental program (Study 1.7.1.5.5) to verify their suitability to produce correctable data over the operating range of the tunnels. In order to gain insight into the universality of the candidate wall configurations, wall interference estimates shall also be made for a representative fighter configuration.
3. As data become available from Study 1.7.1.5.5, calculations shall be made to verify the analytical method's ability calculate and remove the residual

interference from the data. The program shall have the capability to use specified pressure distributions at the wall as a boundary condition.

#### **Study Number 1.7.1.1.14 Drive System Conceptual Design (Mechanical and Electrical Systems)**

**Background:** The requirements for the New Wind Tunnels will be best satisfied by employing compressors that generate low acoustical noise. Low noise compressors inherently turn at low rpm. Low-speed motors are desirable to eliminate gear reductions and reduce acoustical noise. But, low speed implies high torque and large size perhaps leading to more complicated mechanical assemblies. Therefore, the low rpm requirement may produce unwanted compromises in the drive system leading to higher manufacturing, installation, testing, and maintenance costs. To provide guidance for the design, practical limitations of synchronous drive systems below 600 rpm need to be explored.

**Purpose:** To identify practical concepts for motors, variable-frequency drive system, auxiliary cooling and lubrication equipment, and electrical distribution system for low rpm compressors in terms of life cycle cost versus rpm.

**TASK DESCRIPTION:** A trade off study shall be conducted to define viable concepts and design concerns for a lower than 600 rpm drive systems for the Low Speed and Transonic Wind Tunnels based upon government supplied preliminary compressor maps. Items to be considered include but are not limited to:

1. Number and horsepower of drive motors based on practical size and weight versus speed.
2. Mechanical characteristics of rotor and stator assemblies.
3. Cooling requirements and methods for the motors and bearings.
4. Performance, harmonic cancellation, and power factor control of variable speed electronic controllers for both soft-start to synchronize and variable speed up to half power schemes.
5. Overall efficiency to minimize operating costs.
6. Impact of the drive on the utility grid and, if required, concepts to reduce the impact to values acceptable to the utility, i.e., power ramp, power factor, and harmonics.
7. Approximate size, component weight, floor space, and cost of motors, electronic drives, switch gear, harmonic filters, and auxiliary equipment.

#### **Study Number 1.7.1.1.10 Internal Balance Stiffness**

**Background and Purpose:** A feasibility study examining balance envelope and attachment geometry to satisfy required accuracy and load requirements for a series of 6 component internal balances. A result of this activity will be the quantification of achievable accuracies and precision, and other operational and

physical characteristics such as initial deflection constant predictions, diameter, recommended configurations. Identification of balance calibration facility requirements is also necessary.

#### **Study Number 1.7.1.1.2 LSWT Open Jet Aero Performance Study**

Background: The open jet test section will be used for acoustic testing. Some existing open jet test sections, notably DNW, suffer from pulsation problems that limit the maximum speed for operation of the test section. The acoustic testing requirement for the open jet test section in the NWTC is for steady operation over the Mach number range from 0 to 0.6. This study will research the operation of existing facilities to determine the ranges of operation and the limiting factors in order to recommend a way to design an open jet test section capable of meeting the requirements.

Purpose: This study will use existing literature and design method to complete a preliminary design of an open jet test section for the LSWT which meets the aerodynamic performance requirements up to  $M=0.6$  at one atmosphere pressure operation.

##### Task Description:

1. Analyze published and unpublished data from existing open jet wind tunnels to define the design parameter that affect collector and nozzle lip performance with respect to both flow uniformity and steadiness
2. Define candidate concepts for the LSWT Open Jet Test Section Cart
3. Define a test program required to verify and/or develop the Open Jet Test Section.
4. Document results of the study.

#### **Study Number 1.7.1.1.4 TSWT PES Acoustical Suppression Study**

Background: The plenum evacuation system (PES) is responsible for moving a great volume of air in the vicinity of the test section, therefore it has a large potential to generate and radiate noise into the test section. Since the background noise requirements for the acoustic test section, as well as the aerodynamic test sections are very strict, this study is needed to prevent any problems that may arise from the PES.

Purpose: This study will estimate TSWT PES noise generation, propagation paths and intensities, and attenuation devices required to reduce noise radiated into the test section to acceptable levels. A second objective is to reduce noise radiated into occupied areas.

##### Task Description:

1. Determine the most likely PES compressor configuration, pressure line, and valve layout and building layout.

2. Estimate compressor source noise using standard sound power level correlations.
3. Estimate valve noise under the most severe conditions using standard valve noise relations
4. Analyze propagation of the resulting noise field into the plenum and test section to determine the sound pressure level in the test section. Evaluate attenuation required with respect to test section acoustic testing requirements.
5. Analyze propagation of the resulting noise field in the enclosure building to determine sound pressure levels at various locations. Evaluate attenuation required with respect to occupancy requirements.
6. Integrate attenuation concepts required by both test section and building occupancy requirements to the PES compressors, piping, valves, building, plenum, etc. as required to meet the noise requirements
7. Document the results.

#### **Study Number 1.7.1.1.11 TSWT Choke & Re-entry**

*TASK DESCRIPTION NOT YET DEVELOPED.*

#### **Study Number 1.7.1.1.12 Boundary Layer Treatment for Semi-Span and Ground Effects Testing**

**Background:** In order to achieve maximum Reynolds number, tests will be conducted in both the LSWT and TSWT using half span models attached to the external balance. (It is not anticipated that there will be a requirement for side wall mounted models.) To achieve correct similitude, the boundary layer along the tunnel floor and/or the model symmetry plane must be properly accounted. While this test technique has been successfully used for some programs, particularly in Europe, it is not routinely used in most US wind tunnels. Therefore, a study is needed to define the implications and subtleties of semi-span testing so that the correct capability can be designed into the facilities.

**Purpose:** Prepare design requirements needed to satisfy three testing situations, (1) half model testing in the LSWT, (2) half model testing in the TSWT, and (3) testing in ground effect in the LSWT.

**TASK DESCRIPTION:** Conduct a literature search for information connected with half model and ground effects testing. Conduct interviews, as appropriate, with practitioners of the two test types. Integrate and synthesize the information to define appropriate design requirements and operational procedures for the two wind tunnels to achieve the data accuracy and tunnel productivity requirements. Identify any technology developments (hardware or technique) needed to improve current practices.

#### **Study Number 1.7.1.1.5 Productive Model Study**

**Background:** Poor model design, handling and configuration change processes have historically been a barrier to high productivity in wind tunnels. Maximum productivity is an important feature of the new National Wind Tunnel Complex. By determining as early as possible the model activities and component requirements necessary to ensure the overall productivity of the Complex, decisions about model design can be made in light of the possible ramifications of those decisions.

**Purpose:** To maintain the overall tunnel productivity requirements of the National Wind Tunnel Complex, the amount of time allotted to perform model changes, maintenance, and inspections will be tightly controlled. The average model change time (at the time of this writing) over the life of the test will be limited to 25-30 minutes. To achieve this average, careful attention will have to be paid during the design phase to the ease and speed of model changes. Increased (if not full) model automation, reduction or elimination of external fasteners (that must be filled with slow hardening fillers), improvements in filler technologies, etc., will all be considered for a variety of model types. Also, data collection techniques will need to be examined, to determine if mechanical disconnects will be satisfactory for repeated model entries, or if optical, on-board storage, or telemetry techniques, etc., will be needed to insure productivity. Any other technology or operational strategy that can be employed to achieve the productivity goals of this complex will be considered as well.

**TASK DESCRIPTION:** Several benchmark models and test plans must be defined, including general size, loads, test matrices, deflection limits and finish requirements, and any other information that would influence a model design. These generic configurations should include a transport (with and without Turbine Powered Simulators), fighter, missile, acoustics models with hot flow, propulsion integration models with internal sealing requirements, etc. Contour need not be furnished at this stage, except to define the available space envelope of the given model. These specifications will be turned into a "typical model request" and, along with the requirement for productivity, will be contracted out to one or, ideally, several model design organizations.

#### **Study Number 1.7.1.1.17 Continuous Sweep Data Study**

**TASK DESCRIPTION NOT YET DEVELOPED.**

#### **Study Number 1.7.1.1.6 Constructability of Large Components**

**Background and Purpose:** The Low Speed Wind Tunnel (LSWT) and the Transonic Speed Wind Tunnel (TSWT) require very large structural components

for the pressure shells, isolation valves, compressors, movable plenums, test section carts, and model support hardware. Large forging and close fabrication tolerances, particularly in the high speed legs of the tunnels, are required. Fabrication, machining, and assembly of the large components will be done in the contractor's plant and/or on-site. Fabrication of all pressure containing components shall meet the requirement of the Boiler and Pressure Vessel Code Section VIII. Construction of a facility with these parameters offers considerable technical, cost, and schedule risk.

Both the Transonic Wind Tunnel (TSWT) and Low Speed Wind Tunnel (LSWT) use multiple test section carts as a means for increasing testing production rates. These carts are large structural components, which are transported to and from the model preparation areas using a moveable plenum. When the test section/plenum assembly is inserted back into the tunnel, very close alignment of the test section flow surfaces is required to obtain quality flow. This is particularly critical in the TSWT. There is a concern that maintaining good flow might be difficult with this arrangement because of the large pieces involved.

Task Description: This study is to assess the constructability of the large components and to recommend practical and cost effective construction approaches. The contractor shall develop a top level fabrication plan that includes shop and on-site fabrication, the approach to maintain the required close tolerances, and transportation for material and completed hardware to the site. The contractor shall identify size, quantity, and quality of materials and potential suppliers. The capability of suppliers to provide the quantity and quality of materials shall be assessed. The contractor shall identify potential fabricators of the pressure shells, the movable plenums, test section carts, and the model support hardware and develop a feasible fabrication schedule and cost estimate for these components. A cost and schedule trade-off study shall be performed for shop vs. site fabrication/machining due to a more limited site access than recommended in the fabrication plan. Technical, cost, and schedule risks shall also be identified. Consideration shall be given to subcontracting parts of this study to outside consultants with expertise in supplying and fabricating components in this study.

This effort requires an evaluation of the concept for interchanging integral test section carts in the Concept D TSWT configuration. It requires that the criteria for specifying manufacturing tolerances and alignment tolerances for the test section carts in the TSWT be investigated. Preliminary specifications of the required manufacturing and alignment tolerances and an assessment of the feasibility and practicality of obtaining these tolerances during construction and assembly are required. Maintenance of required tolerances over a period of routine tunnel operation must also be addressed. Concepts are to be developed for automatically aligning the components in the tunnel during installation. Evaluate cost impacts on current facility budget estimates.

## **Analytical Tool Development**

### ***Study Number 1.7.1.2.1 LSWT Dynamic Model***

#### **Background:**

**Purpose:** The objective of the LSWT dynamic math modeling study is to develop a model which accurately simulates the pressure, temperature, and Mach number processes to the extent that the model can be used to evaluate and validate the controls software and strategies.

**Task Description:** The dynamic math model is a design and analysis tool which should be initiated at the beginning of the project with development being carried through all phases including facility operation. In the initial study phase a basic lumped parameter model would be developed. The initial model would not operate in real-time. This model would include a preliminary model of the following tunnel process elements:

1. **Lumped Parameter Model** - There are two types of dynamic math models, the lumped parameter model and the distributed parameter model, which have been used for wind tunnel modeling. The lumped parameter model is the type commonly used and is recommended for the LSWT.

The lumped parameter model which divides the tunnel into a few control volumes and uses pressure loss coefficients from a static loss model along with the equations of state to determine the inflow and outflow from these control volumes is the most commonly used and the most successful. Temperature changes such as those associated with pressure changes would be included in the lumped parameter model. This type of model has been used to model the Ames 11 Ft tunnel, AEDC 16T, MSWT, NTF and ETW along with several others.

The plant line volumes would be divided into a system of control volumes which would be important to the facility operating process. Pressure loss coefficients obtained from static loss models would be used along with the equations of state to determine the inflow and outflow from these control volumes. Temperature changes such as those associated with pressure changes would be included in the lumped parameter model.

2. **Compressor Aerodynamic Model** - The compressor model would include a preliminary compressor map with off-design points being calculated through scaling laws.
3. **Compressor Actuator Model** - Control actuators such as those for the inlet guide vanes and stator blades would be modeled as typical first order system. Part of the initial studies would be to evaluate the effects of IGV and stator blade actuator time constants on controllability and productivity.
4. **Speed Control System Model** - This model would simulate the speed control system dynamics, i.e. how fast the system could change rpm.

5. Cooler Model - Since the cooler generally has a time constant which is much slower than the other process parameters this would be a relatively simple model.
6. Pressure In-Bleed and Discharge System Line Model - These models would include lumped parameter models of the lines connecting the tunnel pressurization lines and discharge lines.
7. Tunnel In-Bleed and Discharge Valve Flow Models - These models would include the flow characteristics of the tunnel pressurization and control valves. It would be used to verify the sizing and controllability of the facility.
8. Tunnel In-Bleed and Discharge Valve Actuator Models - These models would include a simulation of the time constants or actuation speeds for the valves used in all tunnel operations including control and isolation.
9. Test Section Model - The LSWT modeling effort will include versions for both the closed-jet and open-jet test section configurations.
10. Test Article Model - One of the most important math models is the simulation of the changes in drag associated with changes in model attitude and the speed of the model movement. This allows evaluation of continuous pitch and pitch pause testing along with evaluation of control strategies, control actuator speeds, and valve sizes.
11. Control System Model - During the early phases of math model development a control system must also be developed in order to interface with the modeled elements and to test controllability.

#### **Study Number 1.7.1.2.2 TSWT Dynamic Model**

##### **Background:**

**Purpose:** The objective of the TSWT dynamic math modeling study is to develop a model which accurately simulates the pressure, temperature, and Mach number processes to the extent that the model can be used to evaluate and validate the controls software and strategies.

The objective of the TSWT Plant Math Model is to develop a plant model which accurately simulates the plant functions to the extent that the model can be used to evaluate and validate the controls software and strategies.

**Task Description** The dynamic math model is a design and analysis tool which should be initiated at the beginning of the project with development being carried through all phases including facility operation. In the initial study phase a basic lumped parameter model would be developed. The initial model would not operate in real-time. This model would include a preliminary model of the following tunnel process elements:

1. **Lumped Parameter Model** - There are two types of dynamic math models, the lumped parameter model and the distributed parameter model, which have been used for wind tunnel modeling. The lumped parameter model is the type commonly used and is recommended for the TSWT.

The lumped parameter model which divides the tunnel into a few control volumes and uses pressure loss coefficients from a static loss model along with the equations of state to determine the inflow and outflow from these control volumes is the most commonly used and the most successful. Temperature changes such as those associated with pressure changes would be included in the lumped parameter model. This type of model has been used to model the Ames 11 Ft tunnel, AEDC 16T, MSWT, NTF and ETW along with several others.

The plant line volumes would be divided into a system of control volumes which would be important to the facility operating process. Pressure loss coefficients obtained from static loss models would be used along with the equations of state to determine the inflow and outflow from these control volumes. Temperature changes such as those associated with pressure changes would be included in the lumped parameter model.

2. **Compressor Aerodynamic Model** - The compressor model would include a preliminary compressor map with off-design points being calculated through scaling laws.
3. **Compressor Actuator Model** - Control actuators such as those for the inlet guide vanes and stator blades would be modeled as typical first order system. Part of the initial studies would be to evaluate the effects of IGV and stator blade actuator time constants on controllability and productivity.
4. **Speed Control System Model** - This model would simulate the speed control system dynamics, i.e. how fast the system could change rpm.
5. **Cooler Model** - Since the cooler generally has a time constant which is much slower than the other process parameters this would be a relatively simple model.
6. **Pressure In-Bleed and Discharge System Line Model** - These models would include lumped parameter models of the lines connecting the tunnel pressurization lines and discharge lines.
7. **Tunnel In-Bleed and Discharge Valve Flow Models** - These models would include the flow characteristics of the tunnel pressurization and control valves. It would be used to verify the sizing and controllability of the facility.

8. Tunnel In-Bleed and Discharge Valve Actuator Models - These models would include a simulation of the time constants or actuation speeds for the valves used in all tunnel operations including control and isolation.
9. Choke Flap Model - This model would be used to simulate the choke flaps and evaluate their effectiveness in control along with associated energy cost.
10. Test Article Model - One of the most important math models is the simulation of the changes in drag associated with changes in model attitude and the speed of the model movement. This allows evaluation of continuous pitch and pitch pause testing along with evaluation of control strategies, control actuator speeds, and valve sizes.
11. Control System Model - During the early phases of math model development a control system must also be developed in order to interface with the modeled elements and to test controllability.

#### ***Study Number 1.7.1.2.3 Aux. Systems Dynamic Model***

***TASK DESCRIPTION NOT YET DEVELOPED.***

#### **Study Number 1.7.1.2.4 Productivity Studies LSWT & TSWT**

**Background:** Maximum productivity is an important feature of the new National Wind Tunnel Complex. By determining as early as possible the components and component requirements necessary to ensure the overall productivity of the Complex, decisions about design and management can be made in light of the possible ramifications of those decisions.

**Purpose:** This activity will integrate the various component and sub-system productivity studies that have been completed to date into a system level productivity sensitivity study.

**TASK DESCRIPTION:** This study will incorporate all technical productivity drivers (such as cart performance, data rates, etc.) and scheduling drivers (test section scheduling, maintenance, manpower utilization and availability, various assumed model arrival schedules) into a partitioned simulation of each tunnel. Furthermore, any potential cross coupling effects from having two tunnels sharing common resources such as physical space (i.e., loading docks), personnel, equipment and so on will be identified and factored into this simulation.

A time and motion study designed to quantify productivity, suggest procedures for critical activities and determine the effectiveness of the current concept will be performed. This type of study will be performed for each tunnel, and will

consider the various types of models and test programs to be accommodated. It is envisioned that a part of this study will be performed in a non-linear, stochastic simulation environment. Reliability and maintenance (MTBF and MTTR), fluctuations in user demand, and availability of resources to meet that demand may be examined in this fashion. Optimizations of design point operations and the impact of off design point operations will also be evaluated in this fashion. Output from this portion of the task will not be sensitivities, but rather average results for the entire complex over a specified time.

#### **Study Number 1.7.1.2.5 CFD Model of TSWT High Speed Leg (Tool)**

**Background:** To satisfy the flow quality and performance requirements for the TSWT, considerable care must be exercised in the design to specify acceptable contours and manufacturing tolerances of the contraction, nozzle, test section, model support, choke, and diffuser sections of the tunnel. Computational fluid dynamic modeling of the test leg will aid in developing the specifications and reduce the risk of missing the performance and quality requirements.

**Purpose:** To provide the capability to estimate the aerodynamic flow quality, performance, and acceptable construction tolerances for various configurations of the test leg components over the operating range of the tunnel.

#### **TASK DESCRIPTION:**

1. Develop CFD computer program structured in a series of modules to allow independent computations of the flow properties of each component of the test leg (contraction, nozzle, test section including slot geometry, model support strut and plenum air re-entry region, trim tab and choke finger section, transition, and high speed diffuser) but with module to module compatibility such that the downstream values of one component can become the upstream conditions of the next component in a coupled and iterative sense when appropriate. The ability to easily change the component geometry is essential to the successful use of the program. The programs will be used to evaluate the effect of geometric changes of the components of the performance and flow quality as a function of test section Mach number (0.2 to 1.5) and total pressure (0.07 to 5 atmospheres). Therefore, as a minimum, the iterative solution of inviscid equations coupled with the boundary layer equations is required.
2. Calculate the flow properties of the TSWT baseline test leg configuration to determine its potential for meeting the flow quality requirements. If the flow quality and/or performance estimates are not confirmed, provide suggested contour changes to achieve the specified performance.

3. Using results from the TSWT pilot tunnel (WBS 1.7.1.5.2), verify the previous calculation capability and extrapolate the results to the conditions of the full scale tunnel.

#### **Study Number 1.7.1.2.6 Model Support System Math Model**

**Background and Purpose:** The objective of the model support system (MSS) math modeling study is to develop a analytical tool for simulating the dynamic motion of the rear strut model support systems and floor mount model support systems for both the Low Speed Wind Tunnel (LSWT) and Transonic Wind Tunnel (TSWT) - four models. The models will be used to evaluate and validate the controls software and strategies. The intent of this study is to develop the initial math models for the model support systems, which will later be integrated into the overall tunnel controls math models. The math models will be expanded and refined as the design is developed, construction progresses, and operations begin.

**Task Description:** The dynamic math model is a design and analysis tool which is initiated at the beginning of the model support system design process with development being carried through all phases including system operation. The initial model may or may not run in real time. The model will include the following elements:

1. Simulation of the torque (or force) characteristics and moving mass characteristics of the MSS drive motors (either electric or hydraulic) for both pitch and roll on the rear strut systems and both pitch and yaw on the floor mount systems. The torque limits and speed limits of the drive systems will be included in the models.
2. Simulation of the electrical or hydraulic line characteristics that impact the dynamic motion of the system.
3. Simulation of the mass of all significant moving elements of the system.
4. Simulation of the variation of the test article forces and moments with angle of attack, sideslip angle and dynamic pressure.

#### **Conceptual Design Development Activities**

##### **Study Number 1.7.1.3.1 Model Attitude Measurement Development**

**Background:**

**Purpose:** The objective is support studies and programs of instrument development of optical and non-contact methods of making attitude measurements.

**Task Description:** Approach for this instrument development would be to let contracts for design work and building of prototype units with a laboratory verification of measurement performance.

### **Study Number 1.7.1.3.2 Isolation Valves**

**Background:** To achieve the productivity requirements of the NWTC, large valves upstream and downstream of the test section/plenum will be required to allow removal of the test section/plenum from the circuit without bringing the complete circuit to atmospheric pressure.

The valve requirements are as follows: The valves must seal the circuit under both vacuum (0.07-atm) and pressure (5-atm) conditions with sufficient reliability and integrity to allow personnel to safely work in the plenum area while the valves are closed and the circuit pressurized/evacuated to the maximum conditions. It is anticipated that for the LSWT the valves could be located in a rectangular section just upstream and downstream of the 20 by 24 foot test section. In the TSWT circuit the minimum upstream locations is anticipated to be in a transitional (circular to rectangular) section just upstream of the nozzle; the minimum downstream valve location is anticipated to be in a rectangular diffuser section just downstream of the choke fingers. The valves' activation mechanism, controls, and instrumentation shall be located within the tunnels' pressure shell. The closing or opening cycle to achieve safe conditions is required to be achieved in 3 to 5 minutes.

**Purpose:** To conduct trade studies of possible design concepts to determine an optimum conceptual design which will meet the productivity, safety, reliability, and maintainability requirements of the tunnels.

**TASK DESCRIPTION:** Conduct trade studies of various isolation valve system concepts to address the following issues:

1. Interface and sealing requirements with the pressure vessel, pressure vessel bulkheads, and internal circuit contours.
2. Structural support of the valves in both the open and closed positions.
3. Access for repair, maintenance, and inspection.
4. Instrumentation to monitor position, health, and safety conditions.
5. Fabrication tolerances for critical machined components and interfaces.
6. Constructability, assembly, and checkout
7. Drive mechanism - hydraulic versus electric
8. Power and other utility (e.g., high pressure air, water) requirements
9. Commonalty of components

The study shall provide a preliminary layout showing valve configuration, valve supports, mechanism concept, interfaces with the pressure shell and internal components. A preliminary deflection, stress, sealing, operational, and failure analysis shall be included. Identify high risk issues, and the reasons therefor, which should be addressed in the final design.

### **Study Number 1.7.1.3.7 Data Error Analysis**

#### **Background:**

**Purpose:** The objective of this study is to perform an uncertainty analysis on the critical measurement parameters to ensure the proper data quality will be collected.

#### **Task Description:**

- Define the key critical parameters of both tunnel operations
- Understand the measurement requirements of the critical parameters
- Develop error budgets through an uncertainty analysis for the elements in the measurement chain
- Verify measurement chain elements are available that meet the error budgets
- Combine the analysis data into an uncertainty analysis handbook

### **Hardware/Component Validation**

#### **Study Number 1.7.1.4.3 Turning Vane - Fluid & Acoustical Performance**

##### **Task Description:**

1. Review literature, especially studies of vane set 2 with drive shaft fairing; e.g. AWT and NTF.
2. Design and build 1/10th scale model (about 50-inch diameter) of entire corner.
3. Measure upstream and downstream turning angles and velocity distributions, losses, acoustic attenuation, and wake attenuation.
4. Vary inflow from uniform to established turbulent pipe flow to assess sensitivity to inflow velocity profiles.
5. Study impact of choke-flap wakes on vane set 1. As required conduct appropriate experiments.
6. Vane set 2 with drive shaft and its fairing will be modeled. Minimization of the vane wake is important because of the adverse effect on compressor inflow.
7. Vanes approximately 15% thick with a chord to gap ratio of about 2 as per 40- by 80-ft wind tunnel turning vanes designed by LeRC.
8. Vanes to be tested with and without acoustic treatment.
9. Vanes to be tested with and without catch (FOD) screens.
10. Trade off vanes with acoustic treatment vs. acoustic treatment of walls and acoustic baffles.
11. Concerns:
  - a. At vane set 2 wake effects (aggravated if contain acoustic treatment) on compressor inflow.
  - b. At vane set 1 dynamic loading tends to be worse than at vane set 2.
- Flow visualization could greatly aid this work.

- Measure turning angle or inflow and outflow velocity and flow angle distribution?

#### **Study Number 1.7.1.4.1 LSWT/TSWT Heat Exchanger Aero Verification**

*TASK DESCRIPTION NOT YET DEVELOPED.*

#### **Study Number 1.7.1.4.2 LSWT/TSWT Honeycomb/Screens Verification**

Background:

Purpose: Test, evaluate, optimize the flow conditioning segment for the TSWT.

Task Description:

- Design/fabricate a flow channel with replaceable segments for testing screens and honeycomb.
- Fabricate test elements of screen and honeycomb.
- Conduct tests for turbulence decay and velocity uniformity.
- Use an existing air supply at LaRC.

#### **Integrated Hardware Validation and Testing**

##### **Study Number 1.7.1.5.1 LSWT Pilot Tunnel**

Purpose To verify/optimize the wind tunnel aerodynamic, acoustic, and mechanical performance.

Task Description:

- Construct a scale facility for one atmosphere operation using air. Use model fan (9730).
- Perform a test program including the following elements:
  - Circuit pressure loss with various test section configurations
  - Test section performance, static gradient, uniformity, turbulence, flow angularity
  - Open jet performance--plenum steadiness
  - Acoustic performance--with flow and without using acoustic generators. Determine sound attenuation/propagation characteristics. Develop and test modifications.

##### **Study Number 1.7.1.5.4 and 1.7.1.5.5 LSWT/TSWT Establish Wall Geometry to Minimize Interference**

Background: High Reynolds number and high data quality are primary goals of the TSWT and LSWT. To achieve maximum Re, large models relative to the test section size are required. However, large models induce large wall interference perturbations into the flow field, thereby significantly reducing data quality. Furthermore, both theoretical and experimental studies show that the wall induced interference field is a function of tunnel total pressure, the model

and its support system geometry, model attitude, and the wall configuration. In order to achieve maximum benefit from the tunnels, it is anticipated that a variable geometry wall configuration will be needed. There are two types of variable geometry options. First is a fully adaptable wall in which the wall geometry is optimized for each data point by measuring the wall boundary conditions and iterating through an adapting algorithm to convergence. Small residual interferences could be removed from critical conditions by theoretical adjustments. A second type uses a geometry which is only variable with Mach number and total pressure. The residual interference as a function of the model and its support configuration and model attitude is removed from the data by theoretical calculations only for those conditions deemed critical to the objectives of the test. While the first method has the potential to produce a better quality product, its use is counter to high productivity. In the second method, the wall geometry can be set to predetermined values during test condition changes without affecting productivity. The data quality is anticipated to be only slightly inferior to the first method. While the first requirement of the ventilated wall is to reduce wall interference for large models to correctable values, the wall configuration must not compromise the inflow noise requirements of the wind tunnels.

**Purpose:** To devise a variable-geometry passive test section wall configuration which will allow large span (up to 80% of tunnel width) models to be tested throughout the operating envelope of the tunnels such that the residual wall interference is correctable by theoretical methods to within the error band associated with the flow quality requirements (see Study #1.7.1.3.7).

#### **TASK DESCRIPTION:**

**Task 1** Conduct a literature search to compile available data on wall geometry which can be used to provide insights into wall cross flow and acoustical properties. Using the information available, select promising ventilated geometry's for theoretical and experimental verification. Consideration shall also be given to using a compliant solid wall in either tunnel.

**Task 2** Using the capabilities developed for and in conjunction with Study #1.7.1.1.9, develop a theoretical distribution of wall cross flow properties (or wall angles, if a compliant wall is chosen) which will produce near zero wall interference for the benchmark model configuration (Attributes given in Study #1.7.1.1.9) for a representative range of tunnel test conditions and model attitudes. Develop a test plan for evaluating the performance of selected wall geometry's in minimizing the interference potential and achieving the acoustical noise requirements of the tunnels. Translate the potential cross flow requirements into wall geometry for testing with a suitable representation of the tunnel's test section, plenum, and benchmark model configuration. It is anticipated the development tests will be conducted at conditions near atmospheric

pressure. (It is intended that the effect of tunnel total pressure will be assessed theoretically as part of Study 1.7.1.1.9. However, consideration should be given to examining the total pressure issue in the 0.3-meter tunnel and LaRC when that tunnel becomes available.) Wall interference free data for the benchmark configuration model shall be obtained in a suitably large wind tunnel facility that will duplicate the pressure/Mach number range of the development tests. Both the interference free and developmental tests shall be conducted such that all bias terms associated with model and support geometry, test techniques, instrumentation, and data reduction cancel when the data are subtracted to determine the wall interference. It is unclear at this time whether the floor mounted half-model or a full span model will be the more severe wall interference problem to solve and what the effects of the fillets in the LSWT are. The results of Study 1.7.1.1.9, Task 1 will identify the more severe problem. The experimental program will be structured to investigate the more severe situation. Whether the solution will adequately solve both cases will be determined using the theoretical predictions of Study 1.7.1.1.9. Nevertheless, because of size, two benchmark models may be required to verify the wall configuration, a pressure model from which the spatial variation of interference may be deduced and a force model from which the integrated interference can be measured. The test program shall take full advantage of advancing techniques such as pressure sensitive paint to assess wall and/or model performance. The figure of merit for ventilated wall configurations shall be first, acceptable (correctable by theoretical means) spatial residual interference distribution along with acceptably low (less than 5 dB above turbulent boundary layer) noise generation, and second, simultaneously correctable lift, drag, and pitching moment data throughout the Mach number, model attitude envelope of the tunnels. For the purposes of this study, it shall be assumed that the effects of total pressure on the wall cross flow properties are predictable using the theoretical model. However, once a wall geometry is developed at atmospheric total pressure, consideration shall be given to verifying the configuration in a suitable high pressure facility.

***Study Number 1.7.1.5.2 TSWT High Speed Leg Integration Testing***

***TASK DESCRIPTION NOT YET DEVELOPED.***

***Study Number 1.7.1.5.7 LSWT/TSWT Acoustical Verification Tests***

***TASK DESCRIPTION NOT YET DEVELOPED.***

### **Study Number 1.7.1.5.3 Subscale Compressor for TSWT**

**Purpose:** Verify and optimize the compressor design and performance. Aerodynamic and acoustic parameters will be investigated.

#### **Task Description**

- Design and fabricate a subscale test bed three stage compressor. Procure a motor and drive. Fabricate a test duct with variable resistance (valve or orifices).
- Conduct a test program to evaluate performance, develop a performance map, assess the operational limits, evaluate effects of inlet distortion, measure exit flow quality and acoustic performance.

### **Study Number 1.7.1.5.9 Subscale Compressor for LSWT**

**Purpose:** Verify and optimize the compressor design and performance. Aerodynamic and acoustic parameters will be investigated.

#### **Task Description**

- Design and fabricate a subscale test bed single stage compressor. Procure a motor and drive. Fabricate a test duct with variable resistance (valve or orifices).
- Conduct a test program to evaluate performance, develop a performance map, assess the operational limits, evaluate effects of inlet distortion, measure exit flow quality and acoustic performance.

### **Integrated Studies Schedule Definition**

An integrated schedule for the studies was developed. Numerous brainstorming sessions were used to determine the linkage between the various studies and the design schedule. Predecessor and successor logic was used to determine the time line for the studies. Provided is the Integrated Studies Schedule and its associated Task Entry form. The information provided includes the estimated cost for each study, the anticipated duration, and the calendar time for the study to occur so that the results are available in a timely manner to support the overall design process.

**National Wind Tunnel Complex  
Studies/Conceptual Designs/Program Mgmt Activities**

WBS	Name	Cost (\$K)	Duration	Early Start	Early Finish	Late Finish
1.7	Government Project Management	\$0	1d	18 Aug '93	18 Aug '93	1 Apr '98
1.7.1	Studies and Hardware Validation	\$14,845	1136d	18 Aug '93	27 Feb '98	1 Apr '98
1.7.1.1	Concept Baseline Development and Assessment	\$3,645	603d	13 Oct '93	11 Mar '96	31 Mar '97
1.7.1.1.1	Aerodynamic Lines and Loads Study	\$600	110d	13 Oct '93	23 Mar '94	28 Oct '93
1.7.1.1.1.2	Aerodynamic Lines and Loads - Mid-Term (50%)	\$250	10w	13 Oct '93	23 Dec '93	3 Aug '93
1.7.1.1.1.5	Aerodynamic Lines and Loads - 100%	\$350	12w	27 Dec '93	23 Mar '94	28 Oct '93
1.7.1.1.3	TSWT Acoustic Test Section Concept Study	\$75	66d	13 Oct '93	19 Jan '94	22 Jan '96
1.7.1.1.13	Cart / Test Section / Model Support Integration	\$1,500	145d	3 Aug '94	3 Mar '95	5 Apr '95
1.7.1.1.13.1	Cart / Test Section / Model Support Integration - 50%	\$700	70d	3 Aug '94	10 Nov '94	15 Dec '94
1.7.1.1.13.2	Cart / Test Section / Model Support Integration - 100%	\$800	75d	14 Nov '94	3 Mar '95	5 Apr '95
1.7.1.1.16	External Balance - Envelope & Load Path	\$100	202d	13 Oct '93	2 Aug '94	2 Sep '94
1.7.1.1.8	TSWT Fan Design Studies	\$100	150d	13 Oct '93	18 May '94	29 Apr '94
1.7.1.1.8.1	TSWT Fan Design Study - Phase 1 (ARC/AEDC)	\$75	30d	13 Oct '93	24 Nov '93	3 Aug '93
1.7.1.1.8.2	TSWT Fan Design Study - Phase 2	\$25	8w	24 Mar '94	18 May '94	29 Apr '94
1.7.1.1.7	LSWT Fan Design Studies	\$75	150d	13 Oct '93	18 May '94	29 Apr '94
1.7.1.1.7.1	LSWT Fan Design Study - Phase 1 (ARC/AEDC)	\$50	30d	13 Oct '93	24 Nov '93	3 Aug '93
1.7.1.1.7.2	LSWT Fan Design Study - Final	\$25	8w	24 Mar '94	18 May '94	29 Apr '94
1.7.1.1.9	Wall Interference Studies - Prelim.	\$45	22d	13 Oct '93	12 Nov '93	9 Mar '94
1.7.1.1.14	Drive System Conceptual Design	\$250	205d	26 Nov '93	19 Sep '94	25 Nov '94
1.7.1.1.14.1	Drive System Conceptual Design - Phase 1	\$50	66d	26 Nov '93	3 Mar '94	25 Nov '94
1.7.1.1.14.2	Drive System Conceptual Design - Phase 2	\$200	125d	24 Mar '94	19 Sep '94	25 Nov '94
1.7.1.1.10	Internal Balance Stiffness	\$100	66d	11 Oct '95	10 Jan '96	25 Dec '96
1.7.1.1.2	LSWT Open Jet Aero Performance Study	\$50	110d	13 Oct '93	23 Mar '94	7 Apr '95
1.7.1.1.4	TSWT PES Acoustical Suppression Study	\$100	125d	24 Mar '94	19 Sep '94	25 Nov '94
1.7.1.1.11	TSWT Choke & Re-entry	\$75	122d	20 Sep '94	17 Mar '95	3 Jul '95
1.7.1.1.12	Boundary Layer for Semi-Span Removal (Fluids)	\$35	130d	27 Dec '93	30 Jun '94	29 Apr '94
1.7.1.1.5	Productive Model Study	\$375	110d	31 Mar '95	5 Sep '95	31 Mar '97
1.7.1.1.17	Continuous Sweep Data Study	\$50	126d	7 Sep '95	11 Mar '96	31 Mar '97
1.7.1.1.6	Constructability of Large Components	\$115	84d	27 Dec '93	26 Apr '94	25 Nov '94
1.7.1.2	Analytical Tool Development	\$925	515d	18 Aug '93	6 Sep '95	31 Mar '97
1.7.1.2.1	LSWT Dynamic Model	\$80	211d	18 Aug '93	21 Jun '94	25 Nov '94
1.7.1.2.1.1	LSWT Dynamic Model - Prelim.	\$30	31d	18 Aug '93	30 Sep '93	30 Sep '93
1.7.1.2.1.2	LSWT Dynamic Model - Final	\$50	63d	24 Mar '94	21 Jun '94	25 Nov '94
1.7.1.2.2	TSWT Dynamic Model	\$80	211d	18 Aug '93	21 Jun '94	25 Nov '94
1.7.1.2.2.1	TSWT Dynamic Model - Prelim.	\$30	31d	18 Aug '93	30 Sep '93	30 Sep '93
1.7.1.2.2.2	TSWT Dynamic Model - Final	\$50	63d	24 Mar '94	21 Jun '94	25 Nov '94
1.7.1.2.3	Aux. Systems Dynamic Model	\$75	125d	24 Mar '94	14 Sep '94	27 Sep '96
1.7.1.2.4	Productivity Studies LSWT & TSWT	\$400	469d	13 Oct '93	24 Aug '95	31 Mar '97
1.7.1.2.4.1	Productivity Studies LSWT & TSWT - Phase 1	\$50	40d	13 Oct '93	9 Dec '93	9 Dec '93

**National Wind Tunnel Complex  
Studies/Conceptual Designs/Program Mgmt Activities**

WBS	Name	Cost (\$K)	Duration	Early Start	Early Finish	Late Finish
1.7.1.2.4.2	Productivity Studies LSWT & TSWT - Phase 2	\$50	80d	24 Mar '94	15 Jul '94	29 Apr '94
1.7.1.2.4.3	Productivity Studies LSWT & TSWT - Phase 3	\$50	80d	1 Nov '94	28 Feb '95	31 May '95
1.7.1.2.4.4	Productivity Studies LSWT & TSWT - Phase 4 (Time & Motion)	\$250	125d	1 Mar '95	24 Aug '95	31 Mar '97
1.7.1.2.5	CFD Model of TSWT High Speed Leg (Tool)	\$200	125d	24 Mar '94	19 Sep '94	29 Apr '94
1.7.1.2.6	Model Support System Math Model	\$90	130d	6 Mar '95	6 Sep '95	26 Sep '96
1.7.1.3	Conceptual Design Development Activities	\$1,875	988d	24 Mar '94	27 Feb '98	1 Apr '98
1.7.1.3.1	Model Attitude Measurement Development	\$1,500	501d	4 Mar '96	27 Feb '98	1 Apr '98
1.7.1.3.2	Isolation Valves	\$225	125d	24 Mar '94	19 Sep '94	25 Nov '94
1.7.1.3.7	Data Error Analysis	\$150	110d	1 Nov '94	11 Apr '95	24 Dec '96
1.7.1.4	Hardware/Component Validation	\$650	262d	24 Mar '94	7 Apr '95	3 Jul '95
1.7.1.4.3	Turning Vane - Fluid & Acoustical Performance	\$350	253d	24 Mar '94	27 Mar '95	3 Jul '95
1.7.1.4.1	LSWT/TSWT Heat Exchanger Aero Verification	\$250	262d	24 Mar '94	7 Apr '95	31 May '95
1.7.1.4.2	LSWT/TSWT Honeycomb/Screens Verification	\$50	262d	24 Mar '94	7 Apr '95	31 May '95
1.7.1.5	Integrated Hardware Validation and Testing	\$7,750	905d	18 Aug '93	27 Mar '97	1 Apr '98
1.7.1.5.1	LSWT Pilot Tunnel	\$3,200	756d	24 Mar '94	26 Mar '97	1 Apr '98
1.7.1.5.1.1	LSWT Pilot Tunnel Procurement	\$2,000	252d	24 Mar '94	24 Mar '95	7 Apr '95
1.7.1.5.1.2	LSWT Pilot Tunnel Verification Tests - Phase I (Ops)	\$1,000	252d	27 Mar '95	26 Mar '96	31 Mar '97
1.7.1.5.1.3	LSWT Pilot Tunnel Verification Tests - Phase II (Ops)	\$0	252d	27 Mar '96	26 Mar '97	1 Apr '98
1.7.1.5.1.4	LSWT Open Jet Verification Test	\$200	168d	27 Mar '95	22 Nov '95	7 Dec '95
1.7.1.5.5	TSWT Establish Wall Geometry to Minimize Interference	\$700	88w	15 Nov '93	15 Aug '95	7 Dec '95
1.7.1.5.4	LSWT Establish Wall Geometry to Minimize Interference	\$300	60w	15 Nov '93	26 Jan '95	7 Dec '95
1.7.1.5.2	TSWT High Speed Leg Integration Testing	\$3,000	757d	24 Mar '94	27 Mar '97	1 Apr '98
1.7.1.5.2.1	TSWT High Speed Leg Design/Fab/Install Modifications	\$2,000	253d	24 Mar '94	27 Mar '95	3 Jul '95
1.7.1.5.2.2	TSWT High Speed Leg Verification Tests Phase I (Ops)	\$700	252d	28 Mar '95	27 Mar '96	31 Mar '97
1.7.1.5.2.3	TSWT High Speed Leg Verification Tests - Phase II (ops)	\$300	252d	28 Mar '96	27 Mar '97	1 Apr '98
1.7.1.5.2.4	TSWT Acoustic Test Section Verification Test	\$500	300d	28 Mar '95	4 Jun '96	31 Mar '97
1.7.1.5.7	LSWT/TSWT Acoustical Verification Tests	\$50	108d	28 Mar '95	28 Aug '95	7 Dec '95
1.7.1.5.3	Subscale Compressor for TSWT	\$0	262d	20 Sep '94	20 Sep '95	31 Mar '97
1.7.1.5.9	Subscale Compressor for LSWT	\$0	262d	20 Sep '94	20 Sep '95	31 Mar '97
1.7.1.5.10	Reynolds Number - How Much is Enough?	\$0	880d	18 Aug '93	20 Feb '97	31 Mar '97
1.7.2	Systems Engineering	\$495	321d	18 Aug '93	29 Nov '94	21 Oct '96
1.7.2.1	Project Management Documentation	\$495	321d	18 Aug '93	29 Nov '94	21 Oct '96
1.7.2.1.0	Requirements Frozen	\$0	0d	18 Aug '93	18 Aug '93	18 Aug '93
1.7.2.1.1	WBS Review	\$0	10d	18 Aug '93	31 Aug '93	9 Apr '93
1.7.2.1.2	Assess Current Design Tools	\$25	88d	18 Aug '93	23 Dec '93	17 Feb '94
1.7.2.1.3	Requirements Document	\$0	6w	1 Sep '93	12 Oct '93	21 May '93
1.7.2.1.4	Acquisition Strategy	\$0	10d	13 Oct '93	26 Oct '93	26 Jan '94
1.7.2.1.5	Design Criteria	\$0	22d	13 Oct '93	12 Nov '93	26 Jan '94
1.7.2.1.6	Requirements Sensitivity; How Much is Enough?	\$20	22d	13 Oct '93	12 Nov '93	26 Jan '94

**National Wind Tunnel Complex  
Studies/Conceptual Designs/Program Mgmt Activities**

WBS	Name	Cost (\$K)	Duration	Early Start	Early Finish	Late Finish
1.7.2.1.7	Tunnel Capabilities Required in 2005 - 2045	\$0	22d	13 Oct '93	12 Nov '93	29 Apr '94
1.7.2.1.8	Model Design Criteria	\$0	22d	13 Oct '93	12 Nov '93	21 Oct '96
1.7.2.1.9	Shell Pressure Test	\$0	44d	13 Oct '93	15 Dec '93	29 Apr '94
1.7.2.1.10	Risk Management Study	\$50	44d	15 Nov '93	19 Jan '94	10 Aug '95
1.7.2.1.11	System Engineering Plan	\$0	66d	15 Nov '93	18 Feb '94	29 Apr '94
1.7.2.1.12	Environmental Impact Statement	\$250	261d	15 Nov '93	29 Nov '94	31 May '95
1.7.2.1.13	Complete Program Management Plans	\$50	0d	18 Feb '94	18 Feb '94	29 Apr '94
1.7.2.1.14	Knowledge Management & System Integration	\$100	50d	27 Dec '93	9 Mar '94	29 Apr '94
1.7.2.1.14.1	Knowledge Management Plan	\$50	30d	27 Dec '93	8 Feb '94	1 Apr '94
1.7.2.1.14.2	Establish Design / Data Library (existing data)	\$50	4w	9 Feb '94	9 Mar '94	29 Apr '94
4	PER/Prelim Design	\$0	392d	13 Oct '93	5 May '95	31 May '95
5	Final Design	\$0	477d	8 May '95	31 Mar '97	31 Mar '97
6	Construction	\$0	252d	1 Apr '97	1 Apr '98	1 Apr '98

# NATIONAL WIND TUNNEL COMPLEX Integrated Studies Schedule

[illegible]

**December 31**

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[illegible]



# **ATTACHMENT 7**

## **NATIONAL WIND TUNNEL COMPLEX**

### **SITE SELECTION PLAN**

***(OFFERORS PROPOSAL  
AND  
EVALUATION PLAN)***



**NATIONAL WIND TUNNEL COMPLEX  
SITE SELECTION EVALUATION PLAN**



## Site Selection Evaluation Plan for the National Wind Tunnel Complex

### 1.0 Introduction

This Plan defines the procedures to be used by the Site Evaluation Board in evaluating the proposals received to site the National Wind Tunnel Complex (NWTC).

### 2.0 Board Membership

The following Board members were designated by the Site Selecting Official on \_\_\_\_\_, 1993, Attachment A:

TBD, Chairperson  
TBD  
TBD  
TBD

### 3.0 Responsibility

The Board is charged with the task of reviewing and assessing all pertinent data and information relative to the selection of a Government site as the location for a state-of-the-art subsonic and transonic wind tunnel complex including auxiliary support equipment.

The Site Evaluation Committee will support the Site Evaluation Board in developing the site selection criteria. The Site Evaluation Committee will also develop specific findings, data, and study results, as necessary, to assist the Board in completing the Final Site Evaluation Board Report.

The Board's review, assessment, and findings should be fully documented and available for the Selection Official's review during 1994. The responsibilities and site selection organization is further delineated in Attachment B. The milestones for completing the site selection process are included in Attachment C.

### 4.0 Procedure

The selection process will utilize a three-level organizational structure consisting of Selection Official, Site Evaluation Board, and Site Evaluation

Committee.

A determination and finding process, Attachment D, was utilized to establish that the Government's best interest is served by limiting the site selection to the following existing wind tunnel sites:

Ames Research Center  
Arnold Engineering Development Center  
Langley Research Center  
Lewis Research Center

The above installations will be invited to submit a proposal for locating the NWTC at their site. The proposals will be in response to instructions listed in paragraph 5. It is suggested that the overall proposal (including response with back-up data to the screening criteria and site evaluation criteria) not exceed 150 pages. Responses must be received at the following location within 60 days of the date on the letter requesting proposals.

Mail Delivery

Facilities Study Office (FSO)  
Site Evaluation Committee  
NASA Langley Research Center  
Mail Stop 284  
Hampton, Virginia 23681-0001

Hand Delivery

Facilities Study Office (FSO)  
17 West Taylor Street  
Building 1212, Room 207  
NASA Langley Research Center  
Mail Stop 284  
Hampton, Virginia 23681-0001

## 5.0 Screening and Site Selection Criteria

The Board will use the following criteria, expressed as instructions to the offerors, to initially screen all proposals and then evaluate the remaining proposals. The construction and operating factors will be scored and the environmental and other factors will receive adjective ratings. Additionally, the Site Evaluation Committee will develop a probable life cycle cost for each proposal that is evaluated.

### 5.1 SCREENING CRITERIA

Each offerer wishing to be considered as a possible location for the National Wind Tunnel Complex (NWTC) must provide a map that shows the proposed location and a technical description of their site. As a minimum, the offerer must address the site, transportation, and utility requirements for the NWTC specified below.

### **5.1.1 Site Requirements**

The proposed site must be a minimum of 60 acres of contiguous existing federal property owned by the United States in fee simple with no outstanding interests. Provide documentation from the Environmental Protection Agency (EPA) Regional Office verifying that the 60 acre site is not listed or proposed for listing as a Superfund site or is not subject to closure (and/or corrective action) requirements under the Resource Conservation and Recovery Act (RCRA) or the Hazardous Solid Waste Amendments (HSWA). Provide a letter from the appropriate state regulatory agency verifying that the 60 acre site is not under any state compliance or corrective action requirements.

### **5.1.2 Transportation Requirements**

**5.1.2.1 Airline Access**—Site must be within a 75 mile radius of a major airport that is capable of handling 1500 lb containers. A major airport is a large or medium hub structure as defined by the Federal Aviation Administration (FAA) in the "Airport Activity Statistics of Certified Route Air Carriers" for the calendar year 1991.

**5.1.2.2 Railroad and/or Barge Access**—The site must be within 5 miles of either a navigable waterway or a spur line of an active railroad system.

**5.1.2.3 Highway Access**—The site must be adjacent, within 5 miles, to a four lane highway.

**5.1.3 Utility Requirements**—Provide a letter from the local utility company(s) verifying that they will be able to provide the following utility requirements by July 2000 on a year round, 24 hours per day, 7 days per week basis to the proposed site. These utility requirements listed below are in addition to the current vicinity utility requirements.

**5.1.3.1 Electrical Power**—Support a connected load of 590 MW with a maximum peak demand of 500 MW and an average peak demand of 300 MW with a monthly usage of 40 million KWH. Have a short circuit capacity of 10,000 MVA. Provide a ramp rate of 2 MW/second and an instantaneous load shed of 250 MW for emergency purposes.

- 5.1.3.2 Water Consumption**--Provide make-up water of 7,500 gallons per minute capacity with an average usage of 67 million gallons per month.
- 5.1.3.3 Natural Gas**--Supply a peak demand of 3500 standard cubic feet per minute with an average demand of 200 to 400 scfm. The operating pressure of the delivery system should be approximately 50 psig. The projected annual usage is 100 to 200 million cubic feet.

## **5.2 SITE EVALUATION CRITERIA**

The following site evaluation criteria will be evaluated in accordance with attached Table 1.

### **5.2.1 CONSTRUCTION (ACQUISITION) FACTORS**

Each site must provide any cost factors in 1994 dollars. Specific items that make up the acquisition portion are:

- 5.2.1.1 Weather**--NOAA historical weather data will be used in determining the cost of lost work days. A submittal is not required.
- 5.2.1.2 Transportation Requirements**--Use of existing government owned land eliminates the need to purchase the 60 acres required for construction of the project with the possible exception of land that may be required for transportation. Indicate any restrictions or procedures to transfer use of proposed land or cost if the land must be purchased for the items listed below.
  - 5.2.1.2.1 Railroad and/or Barge Access**--Provide a map(s) showing the relative location of the proposed site to the transportation network and identify the permissible load weights and size limitations for the railroad and barge systems.
  - 5.2.1.2.2 Highway Access**--Provide a map(s) showing the relative location of the proposed site to the transportation network and identify the permissible load weights and size limitations for each road.

- 5.2.1.3 Labor**--Provide data which covers the local applicable labor crafts and Davis-Bacon pay rates.
- 5.2.1.4 Utilities**--Provide information defining the location of the utilities (electrical, water, gas and sanitary sewer) relative to the proposed site. Describe what will be necessary to provide these utilities (water pretreatment, electrical substation, etc.) at the site and the associated cost.
- 5.2.1.5 Supporting Infrastructure**--Locating these facilities in proximity of a supporting infrastructure may eliminate the need to duplicate supporting activities such as:

fire protection  
security  
machine shops  
model shops  
photo lab  
balance calibration labs  
warehouse  
computer support facility--computer system capable of supporting computational fluid dynamics (CFD)

Identify the existence of any of the above supporting infrastructures and describe their capability, condition, capacity, and availability.

**5.2.1.6 Site Conditions**

Site Description--The 60 acre site shall be contiguous, usable property with no natural or manmade barriers or legal constraints that would restrict the proposed construction. The offerer must provide information on the following site characteristics: 1) topography; 2) soil loading capabilities; 3) surface water and drainage; 4) ground; and 5) subterranean water conditions, including depth to ground water and depth to bedrock. Provide the results of any site assessments that would define the geology/soil, seismology, topography, wind load, and hydrology/hydrogeology of the proposed site. Also, provide documentation that verifies the usage of the proposed site over the previous 60 years.

**Noise Abatement**--The chosen site will dictate the methods required to reduce the 85 dBA present at the edge of the 60 acre site to acceptable local noise requirements. Assume the source of the noise is located in the center of the 60 acre site. Define the current noise level restrictions in the area of the proposed site and identify any pending changes to this restriction. Identify the current zoning of the surrounding area and the method being recommended to reduce the noise to acceptable levels for 24 hours per day, 7 days per week operation. If a land buffer is to be used as a method of noise attenuation, identify any restrictions to the transfer of land, the cost of purchase if appropriate, environmental impacts of the noise on the buffer, and an assessment of the method in accounting for atmospheric refraction of the noise outside of the buffer boundary.

**Site Clearing**--The offerer must identify the degree of vegetation or structure(s) to be cleared/demolished and a rough estimate of cost.

## **5.2.2 OPERATING FACTORS**

Each site must provide any cost factors in 1994 dollars unless otherwise indicated. Specific items that make up the operating portion are:

- 5.2.2.1 Airline Access**--Identify all capable airports within a 75 mile radius and describe their characteristics including; number of hours shutdown over the past 5 years due to weather, restrictions on use (including weather), instrumentation, driving distance, hours of operation, air freight capability, etc. Provide a map showing the proximity of the airport to the proposed site.
- 5.2.2.2 Utilities**--Provide historical (last 25 years) information on utility usage including peak, average, and minimum demand (identify the month that the peak and minimum occurred), annual usage, ramp rates, and base requirements in then year dollars. Provide information on all utility interrupts (voluntary and involuntary) and reduction in services that affected wind tunnel operations at your location for the previous 10 years and the reasons for these interrupts. Using the quantity descriptions found in Section 5.1 SCREENING CRITERIA provide

information on the following:

- 5.2.2.2.1 Electrical Power**--Provide 1993 industrial rate structure, current negotiated rate structure at that federal facility including terms and conditions of any interruptable service, and projected uninterruptable July 2000 negotiated rates (include escalation rates) if this project is constructed at that site. Also, provide the impact of Public Law 102-486 on the proposed negotiated rate. Provide historical data to support the stability of the industrial and negotiated rate structure in then year dollars. Provide plans to operate the NWTC in conjunction with existing facilities to mitigate the cost of electrical power. Provide details of in place strategies/tools that are currently being used to mitigate utility costs. Offerors will be required to have the local electric utility present their plans to modify their system to meet the power requirements. Include your proposal for distribution of demand and energy charges among the users at your installation including NWTC.
- 5.2.2.2.2 Water Consumption**--Indicate the source and nature of the make-up water. Indicate if drinking water is available for a total of 200 people at the facility.
- 5.2.2.2.3 Natural Gas**--Provide 1993 industrial rate structure, current negotiated rates at that federal facility, and projected negotiated rates if this project is constructed at that site. Provide historical data to support the stability of the industrial and negotiated rate structure in then year dollars.
- 5.2.2.3 Local Skilled Labor**--Provide service contract labor rates from a current wind tunnel operation contract. Provide data (and validating documentation) required in Table 2 from your installation. Provide any historical information on availability and stability of labor for operations of a similar type of industrial complex.

**5.2.2.4 Supporting Infrastructure:**

**5.2.2.4.1 Infrastructure--**Identify and describe any existing infrastructure and required changes that may support the maintenance and operation of this facility for the supporting activities such as:

fire protection  
security  
machine shops  
model shops  
photo lab  
balance calibration labs  
warehouse  
CFD support for the NWTC  
waste disposal  
waste water disposal (sanitary, storm water, and cooling tower)

**5.2.2.4.2 Shared Work Force--**Provide historical data on a shared work force including wind tunnel operations and similar operations as listed above which demonstrate how using this technique and other management tools and techniques were used to mitigate the fluctuations in work loads. Identify any existing similar operations that may provide a resource to supplement operations personnel on a part-time and full-time basis.

**5.2.2.4.3 Management Plan--**Describe how management will integrate the NWTC into the installation's organizational structure.

**5.2.3 ENVIRONMENTAL**

The land being proposed as a potential site should be free of significant environmental issues. Provide information and state environmental agency certification where appropriate on any known or pending environmental issue that might result in delays in completing an Environmental Impact Statement.

**5.2.3.1 Flood Plains and Wetlands--**The offerer must provide a

map with contours showing the 100 and 500 year flood plains and indicate the elevation of the proposed site relative to these flood plains. Indicate the percentage of the site within the 100 and 500 year flood plains. The offerer must verify with the state and/or Corps of Engineers whether the 60 acre sites contain wetlands. If the site contains wetlands, provide a map showing their location and indicate how any wetlands impacts could be mitigated.

- 5.2.3.2 Threatened and Endangered Species**--The offerer must obtain from the U.S. Fish and Wildlife Service or appropriate state agency a list of threatened and endangered species located on the 60 acre site. The likelihood of the occurrence of these species on the site must be evaluated by the offerer.
- 5.2.3.3 Construction Traffic**--The offerer must describe the possible routing of the construction traffic. Indicate if new roads will be built and the degree to which traffic will travel through existing residential neighborhoods. Provide a map indicating the routing of construction vehicles and the location of residential areas.
- 5.2.3.4 Designated Protected Areas**--The offerer must identify any protected area(s) located within a 10 mile radius of the 60 acre site. Examples of protected areas are: wild and scenic rivers; city, state and national parks; national forests; etc. Provide a map showing the relative location of any of these protected areas to the site and construction traffic routing.
- 5.2.3.5 Waste Water Disposal**--The wind tunnels will require discharging of cooling water during routine cooling tower maintenance. The offerer must verify with the state environmental agency the following factors regarding the necessary National Pollutant Discharge Elimination System (NPDES) discharge permit: 1) availability for such a discharge; 2) any restrictions with such a discharge; 3) requirements for permits and an estimate of time frame and cost to obtain these permits; and 4) any other considerations which may affect cost, schedule, or operations. Also, the offerer must either verify that existing sanitary treatment facilities have adequate

capacity to handle the increased waste load for 200 people located at this facility or identify how the sanitary wastes will be treated. Lastly, identify how the storm water will be treated.

- 5.2.3.6 Water Supply**—The offerer must verify that the water supply requirements for construction and operation of the NWTC would not cause significant adverse impacts to local surface or ground water supplies, or create adverse water rights concerns.
- 5.2.3.7 Hazardous and Toxic Wastes**—The offerer must provide a list of underground storage tanks and any associated monitoring wells in or adjacent (within 100 feet) to the proposed site. Indicate if the tanks are in operation or closed and list their contents. Provide a copy of the closure documentation if the tanks are closed. The offerer must provide information on any known soil or ground water contamination in the area. The offerer must verify with their EPA Regional Office that no known RCRA or Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) violations or any other actions exist at the site. The offerer must list enforcement actions and compliance agreements or consent orders.
- 5.2.3.8 Permits and Licenses**—The offerer must provide a list of federal, state, and local permits and licenses required to construct and operate the NWTC.
- 5.2.3.9 National Environmental Policy Act (NEPA) Issues**—The offerer must describe experience with preparing and getting approval of an Environmental Impact Statement. Identify all agencies involved with the oversight of the recommended site's activities. Describe experience with the public and agencies in the site area on other NEPA document preparation, e.g., acceptability of this technology to the local populace, anticipated areas of controversy, etc.
- 5.2.3.10 Air**—The offerer must indicate any federal or state permit or other operating requirements regulating the use of natural gas as fuel for equipment (i.e. supply air regulations concerning this area).

## **5.2.4 OTHER FACTORS**

**5.2.4.1 Community Conditions**—Characteristics of the community where the facility complex will be located is important. This category will address the quality of life as defined by:

**5.2.4.1.1 Tax Structure**—Identify applicable taxes on both the facility operations and the individual employees of the facility complex. Include all "User Fees", state and local income tax rates, sales taxes rate, property tax rates, etc. Provide the identified tax and user fee information.

**5.2.4.1.2 Educational Infrastructure**—Describe the local school system and its performance against any national standards. Describe the opportunities for continuing education of the work force, both skilled labor and degreed professional, and availability of outside technical expertise within commuting distance of the proposed site.

**5.2.4.1.3 Real Estate**—Provide information on average housing in the community as well as information on the Cost of Living Index. Describe size, general description, housing density, average sales price, average time from listing with real estate agent to closure, number of available housing units and percent occupancy.

**5.2.4.1.4 General Community Infrastructure**—Describe opportunities for shopping, entertainment, recreational activities, and cultural events/activities.

**5.2.4.1.5 Community Support**—Document acceptability and public support for the NWTC by submitting letters from the local city and county governing units. The offerer must include an endorsement by the appropriate municipal planning body and the Chamber(s) of Commerce.

**5.2.4.2 Future Encroachment**—Provide a master plan showing the

location of industrial, commercial, and residential areas surrounding the proposed site including all future land use. Indicate the consistency of past zoning and future prospects that the land will remain as indicated to ensure avoidance of encroachment issues.

- 5.2.4.3 Historic Cultural Resources**—Offerer, on the basis of official survey, shall certify that the offered land is free of historic cultural resources under terms of the National Historic Preservation Act. If such resources exist on the offered land, offerer shall describe significance and state-approved management plan. Offerer shall consult with the particular State Historic Preservation Officer (SHPO) and provide a letter of concurrence from the SHPO relative to 1) such absence of historic cultural resources, or 2) the management plan for any such resources that are present on/in this property. This certification shall also pertain to any registered or eligible landmarks or districts in the vicinity that would restrict or effect the development of the offered property.

**Table 1 Criteria Rating**

Each scored category = 100 points

<b><u>Construction (Acquisition) Factors</u></b>	<b><u>30%</u></b>	<b><u>Operating Factors</u></b>	<b><u>70%</u></b>
Weather	10	Airline Access	10
Transportation Requirements	20	Utilities	40
Rail/Barge			
Highway			
Labor	30	Labor	30
Utilities-Delivery	10	Supporting Infrastructure	20
Infrastructure	10		
Site Conditions	10		
Land Costs	10		
Buffer			
Transportation			
Demolition			
<b>Total</b>	<b>100</b>	<b>Total</b>	<b>100</b>

**ELECTRICAL POWER RATING PROCEDURE**

The following procedures will be utilized to "equalize" the electrical power rates from Federal Facilities with and without current special negotiated rates with local power companies:

- 1) Request that offerors submit 1993 Industrial Rate Structure, current negotiated rates (if in existence), and projected rates assuming that the NWTC commences operation July 2000.
- 2) In order to create a "level playing field", the site evaluation committee will "construct" a negotiated rate (for sites without one) by utilizing the average submitted ratio of negotiated rates to industrial rates.
- 3) The Site Evaluation Committee will evaluate all submitted electrical power rates. However, the evaluation rating process will recognize that existing industrial and existing negotiated rates are more credible than "constructed negotiated rates" and July 2000 projected rates.

**Environmental** (Adjective Rating)

Excellent      Good      Fair      Poor

**Other Factors** (Adjective Rating)

Excellent      Good      Fair      Poor

National Wind Tunnel Complex  
Site Selection Evaluation Plan

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<u>Adjective Rating and Numerical Scores</u>		
<u>Adjective Rating</u>	<u>Adjective Definition</u>	<u>Numerical Score</u>
Excellent	A comprehensive and thorough proposal of exceptional merit with one or more major strengths. No weaknesses or only minor correctable weaknesses exist.	91-100
Very Good	A proposal which demonstrates overall competence. One or more major strengths have been found, and strengths out balance any weaknesses that exist. Any major weaknesses are correctable.	71-90
Good	A proposal which shows a reasonably sound response. There may be strengths or weaknesses, or both. As a whole, weaknesses, not offset by strengths, do not significantly detract from the Offeror's response. Major weaknesses are probably correctable.	51-70
Fair	A proposal that has one or more weaknesses. Weaknesses have been found that out balance any strengths that exist. Major weaknesses can probably be improved, minimized, or corrected.	31-50
Poor	A proposal that has one or more major weaknesses which are expected to be difficult to correct, or are not correctable	0-30

## 6.0 SITE SELECTION EVALUATION FACTORS - NWTC

The following guidelines serve as an aid to the Evaluation Board in providing adjective ratings for the scored site selection factors. The site specific life cycle costs will be developed by incrementing/decrementing from the model developed for the NWTC cost estimate.

### CONSTRUCTION

#### Weather

- o Number of lost days/year

*NOAA data will be used to determine the number of non work days per year.*

*Higher scores are given to proposed locations that have fewer nonworkdays due to weather. The relative cost impact will be determined by combining this factor with labor (for costing only) and using a construction cost index such as Means to determine the area multiplier.*

#### Transportation

- o How many modes does the site have
- o Distance from terminus to the site
- o Load and size capacity of the transportation mode
- o Upgrades/Repairs necessary

*Highest scores will be given to proposed locations that have the transportation requirements/capacity in place with no modifications/repairs needed. Scores will diminish as the cost to install goes up or the effect is to increase the construction costs. Costs to correct deficiencies will be determined by the committee based on the data provided by the offeror.*

#### Labor

- o Labor costs
- o Have skills needed

*Highest scores are given to proposed locations that have the lowest labor costs. Construction cost indexes ,Davis Bacon Wage Decisions, Union agreements for the local area, and Bureau of Labor Statistics wage data will be used to obtain the cost data.*

#### Utilities

- o Cost and distance to bring to the site
- o Cost to strengthen/enlarge existing service

*Highest scores will be given to proposed locations that have the capacity in place with no modifications/repairs needed. Scores will diminish proportionately to the amount of additional construction needed. Costs to correct deficiencies will be provided by the offeror. The offeror will provide information as to whether the costs will be paid up front or recovered in the rate structure.*

### Infrastructure

- o Number of items satisfying the requirement
- o Capability/Capacity to meet the requirements

*Highest scores will be given to proposed locations that offer the most existing infrastructure that defrays the cost to the project to provide. The evaluation committee will determine the value of the existing infrastructure to factor into the life cycle cost.*

### Site Conditions

- o Number and relative value of factors that affect the cost (i.e. seismic, winds, soil loading, buffer land [or proposed alternative])
- o Availability, cost, and zoning of buffer land
- o Required demolition costs

*Highest scores will be given to proposed locations whose site provides the combination of conditions leading to the lowest cost of construction. Multipliers to the NWTC estimate will be determined based on published or other engineering cost data. Alternate methods of noise control will be evaluated on the basis of cost.*

## OPERATING

### Airline Access

- o Number and types of airports within the 75 mile radius
- o Distance from the site
- o Number of hours closed per year due to weather
- o Operating hours per day and week
- o Air freight capability and operating hours

*Higher scores will be given for closeness of the airport to the site, lowest number of weather closures, highest number of daily operating hours, and the number and service of the air freight carriers for all airports.*

### Utilities

- o Current rate structure (elect., gas, and water)
- o Rate history (elect., gas, and water)
- o Restrictions on use (elect., gas, and water)
- o Proposed rate structure (elect., gas, and water)

*The past, present and future rate information will be evaluated along with information from the Department of Energy, the Electric Power Research Institute, and other sources. The offerors will supply information on the rate structure and the potential impact of Public Law 102-486 and other factors on the future rate structure. The most probable cost will be determined and factored into the life cycle cost.*

**Labor**

- o Rate
- o Availability of skills required
- o Stability of employment

*All factors will be considered with highest weight given to lowest labor rates. The ability to recruit and retain the skills required will be assessed. Service contract labor rates, historical rates, and Bureau of Labor Statistics wage data will be utilized to obtain the cost data. The most probable cost will be determined and factored into the life cycle cost.*

**Support Infrastructure**

- o Number/value of items satisfying the NWTC requirements
- o Capability/capacity, availability, and condition of items which support the NWTC

*Higher scores will be given to locations that minimize the NWTC infrastructure investment.*

**Management Plan**

*Highest scores will be given to the location that presents a viable plan and shows a methodology for managing the installation in an efficient manner in the national interest.*

**National Wind Tunnel Complex  
Site Selection Evaluation Plan**

**Table 2: National Wind Tunnel Complex Staff Requirements**

<b>Operations and Maintenance Staff Reqmts.</b>	<b>No. Req'd</b>	<b>College Education</b>	<b>Avg Years Exp.</b>	<b>Base Salary</b>	<b>Fringe Benefits</b>	<b>Salary + Fringes</b>
Project Engineer	18	BS/AE/ME	4			
Test Engineer	9	BS/AE/ME	6			
Industrial Engineer	6	BS/IE/ME	4			
Controls Engineer	3	BS-EE	4			
Computer Scientist	7	BS-CS	4			
Facility Engr. - Mech.	4	BS-ME	4			
Facility Engr. - Elect.	4	BS-EE	4			
Fac. Engr-Comp/ADP	4	BS-CS	4			
Craft Supervisor	4	--	8			
Technical Assistant	7	AA	1			
Mechanic	26	--	4			
Instrument Technician	18	--	4			
Electricians/Operator	22	--	4			
Computer Operator	4	1 yr.	2			
Laborer	3	--	2			
<b>Test Support Staff</b>						
<b>Reqmts.</b>						
Janitor	5	--	1			
Guard	8	1 yr.	2			
Machinist	6	--	4			
Clerk	14	1 yr.	1			
Photographer	2	3 yrs.	3			
Safety/Environ. Engr.	1	BS	2			
Design Engr.	3	BS-ME/EE	3			
Drafter	3	2 yrs.	1			
Q A/Calibration Engr.	5	BS	4			
<b>Administrative Staff</b>						
<b>Reqmts.</b>						
General Manager	1	MS/PhD	16			
Supervisor	5	BS	10			
Personnel	2	BS	3			
Contract	3	BS	4			
Administrator						
Budget Analyst	3	BS	3			
<b>Total</b>	<b>200</b>					

## 7.0 Selection

The Site Selection Official will determine the preferred site after review of the findings incorporated in the report from the Site Evaluation Board. The report will include findings on construction, operations, environmental issues, and other factors. In addition, a probable life cycle cost will be included for each evaluated site. Although life cycle cost is considered to be important, it will not be emphasized in relation to the aforementioned evaluation factors due to the inability to accurately estimate the relative life cycle cost of proposed sites. The site selection decision will be accompanied by a site selection statement developed by the Site Selection Official. The statement will include a summary of findings, the relative importance of all factors, and rationale for selection.

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Chairperson

Other Members:

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TBD

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TBD

Approved: \_\_\_\_\_

John R. Dailey

Charles Adolph



**ATTACHMENT 8**

**NATIONAL WIND TUNNEL COMPLEX**

**PROJECT MANAGEMENT**

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**ATTACHMENT 8.1**

**NATIONAL WIND TUNNEL COMPLEX**

**PROGRAM MANAGEMENT**



## **NATIONAL WIND TUNNEL COMPLEX PROGRAM MANAGEMENT**

Various Program Management options were evaluated. Each option has merits and detractors. The FSO did not recommend a particular Program Management approach because it was judged that that decision belongs with the Program Manager. Provided below are the Project Office activities as defined by the FSO.

### **Studies**

- Complete identification of the areas of technical uncertainty, technology development, and high risk. These are the areas requiring study.
- Complete definition of the studies scopes of work.
- Obtain the proper study contracts
- Provide the engineering guidance of the studies and the transfer of knowledge to the final design team.

### **PER/Preliminary Design**

- Initiate and obtain the Preliminary Design Contract
- Define the NWTC interfaces
- Proceed with the PER/Preliminary Design of the LSWT, the Auxiliary Process Systems, and the associated infrastructure
- Initiate the PER/Preliminary Design of the TSWT at the completion of the key study activities.
- Complete the PER/Preliminary Design execution
- Initiate contracting effort(s) for the final design activities

Staffing estimates to provide guidance and engineering oversight for Studies and PER/Preliminary Design is provided in Figure 1 and Table 1.

- Review Acquisition Strategy with Senior Management of potential sites for concurrence.

### **Select Final Design Approach**

- Consortium of several A/E's
- Multiple A/E designs of the complex for future down-select
- Divide complex into smaller jobs
  - Single/Multiple A/E for each job
  - Integration of design - Government or A/E integration
- Select single A/E

### Select Construction Approach

- Consortium of several contractors
  - Teamed with Government and A/E consortium
  - Build to Print
- Single Prime Contractor
  - New contract
  - Continuation of Design/Build Contract
- Divide Complex into Smaller jobs
  - Contracts
    - Continuation of above through design/build
    - New Contracts
  - Integration
    - Government
    - Integration Contractor
- Government Furnished Equipment
  - Little to None
  - All Major Equipment

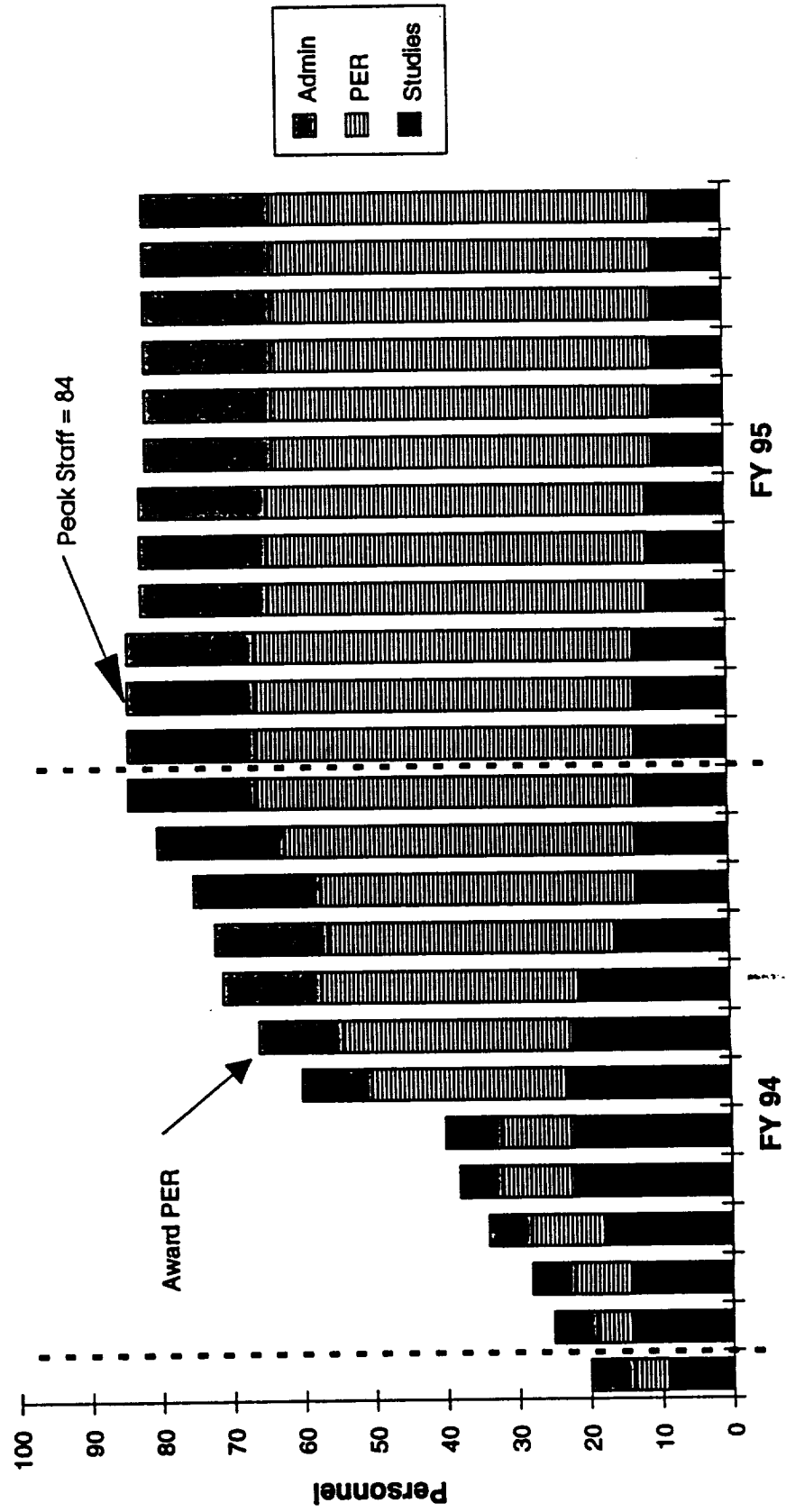
Staffing estimates to provide guidance and engineering oversight for Final Design and Construction were not developed because they are directly dependent upon the contracting method and Project Management approach that are selected.

*Note that the FSO cost estimates were based upon the Single Prime Contractor approach for both Final Design and Construction.*

**Table 1 : Staffing and Skill Mix Required to Implement Studies and PER/Preliminary Design**

<b>SKILL</b>	<b>STUDIES (FY 94-FY 95)</b>	<b>PER (FY 94-FY 95)</b>	<b>TOTAL (Through FY95)</b>
Mechanisms	4	6	7
Structural	4	8	9
Low Speed Aerodynamics	2	3	4
Transonic Aerodynamics	2	3	5
Acoustics	1	2	3
Controls	2	3	3
Fan/Drive System	1	2	2
Fluids/Process Systems	1	4	5
Modeling/Simulation Analyst	1	1	1
Power	1	2	2
Instrumentation	1	3	3
Industrial Engr.	1	1	1
Models	1	1	1
Systems Engineering & Integration	3	8	8
Civil	0	3	3
Software	0	3	3
Admin/Support (includes Admin., clerical, Cost Est., Schedule, Contracts, CAD, and Management)	8	18	18
<b>TOTALS</b>	<b>33</b>	<b>71</b>	<b>78</b>

**Figure 1: Staffing Required to Implement Studies and PER**



**ATTACHMENT 8.2**

**NATIONAL WIND TUNNEL COMPLEX**

**PROPOSED**

**COMMERCE BUSINESS DAILY**

**ANNOUNCEMENTS**



*Proposed*  
*Commerce Business Daily Announcement*  
*For*  
*Studies*



**Indefinite Quantity A/E Services Contract for Studies to support development of state-of-the-art High Reynolds Number Wind Tunnels for the National Wind Tunnel Complex (NWTC).**

POC Henry L. Livas, Jr., Mail Stop 284, 804-864-3718, Langley Research Center, Hampton, VA. The studies consist of preparing all necessary analyses, drawings, experimental tests, cost estimates, and schedules for proposed subsonic and transonic wind tunnels. The studies may include the following areas: (1) data quality; (2) productivity and operating cost; (3) aero and acoustic performance; (4) life cycle cost; (5) experimental validation; (6) facility math models; (7) instrumentation and controls; (8) tunnel circuit/component optimization. All deliverables (including drawings) shall be developed using an electronic database with the capability of electronic transmission to the Office of the Contracting Officer's Technical Representative (COTR).

Firms that meet requirements described are invited to submit SF 254 and 255 within 30 calendar days from the date of publication. Responses must be received NLT 4:30 p.m. of the 30 calendar days with publication day counting as the first day.

The type of contract proposed is an indefinite quantity contract. Individual work orders will be negotiated firm fixed price. Services will be for a 1-year period with an option to extend for two 1-year periods. A minimum fee of \$100,000 will be guaranteed for the contract's base period. The total accumulative A/E fees paid under this contract (including options) will not exceed \$15,000,000. Multiple indefinite quantity contracts may be awarded from this advertisement.

The NASA A-E selection board will apply the following criteria in order of importance:

- (1) Specialized experience and technical competence to accomplish aeronautical wind tunnel designs and studies. Experience shall include design of the following tunnel components and subsystems:

- a. PERFORMANCE AND FLOW QUALITY

- o Tunnel internals impacting test section flow quality, tunnel drive power requirements, initial design/development cost, and operation and maintenance cost:

fan/compressor system; high, low speed, and rapid expansion diffusers; subsonic/supersonic nozzles; turning vanes; flow

**National Wind Tunnel Complex**  
**Proposed Commerce Business Daily Announcement for Studies**

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filling and antiturbulence screens; cooling coils; flow straightening honeycomb; contractions; test sections (vented and unvented, with and without plenum evacuation systems and open jet); model support and model handling systems; liquid and gaseous injection and exhaust system components; debris catcher screens/honeycomb; and acoustic noise suppression

- o Integration of tunnel internal components with the tunnel pressure shell including attachments and penetrations
- o Design and integration with tunnel systems of external process systems, data acquisition systems, and control systems
- o Tunnel pressure shells (pressures to five atmospheres) and its internal aerolines

**b. PRODUCTIVITY**

- o Model handling, preparation, and checkout systems
- o Calibration systems for model instrumentation and balances
- o Tunnel test section access and isolation systems
- o Data recording, reduction, and evaluation systems
- o Automated Tunnel Operating and Control Systems
- o Predictive maintenance systems including diagnostic systems which record trend data of critical tunnel components and tunnel ancillary support systems

**c. RELIABILITY/MAINTAINABILITY**

- o Wind tunnel drive systems, model handling systems, model support systems, isolation systems
- o Automated, integrated process control and data acquisition systems
- o Air compressors, pumps, valves, and cooling systems

d. DATA QUALITY

- o Instrumentation/wiring systems
- o Data acquisition systems
- o Process control systems
- o Acoustic measurement systems
- o Flow quality
- o Background noise level

e. AUXILIARY SYSTEMS

- o High Pressure Air, Heavy Gas, Hydraulic, Gaseous Recovery Systems, Vacuum systems, and Cooling Water
- o Utilities: Electrical, Water, and Natural Gas

- (2) Proven ability to develop accurate wind tunnel construction cost estimates and schedules including use of historical data.
- (3) Past record of performance on aeronautical wind tunnel contracts with NASA, other Government agencies, foreign government agencies and private industry;
- (4) Capacity of the firm to accomplish studies estimated to cost \$50,000 to \$250,000 within 60 days; and \$250,000 to \$1,000,000 within 270 days.
- (5) Location of the firm (the A-E shall specify the location of the office where the work will be performed);
- (6) Familiarity with NASA and DOD, and private industrial installations that currently have wind tunnels;
- (7) Volume of work previously awarded to the firm by NASA with the object of effecting an equitable distribution of NASA A-E contracts among qualified firms, including minority-owned firms and firms that have prior NASA contract. This is not an RFP.

**This contract is not set aside for Small Businesses. Large business A/E firms/teams shall submit an acceptable small business and small disadvantaged business subcontracting plan prior to award.**

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See Note 24. Provisions of Note 24 apply to this notice except that (a) in the sentence beginning "Selection of firms for negotiations," the fourth additional consideration listed is changed to read: "(4) past experience, if any, of the firm with respect to performance on contracts with NASA, other Government agencies, and private industry;" and (b) in the last sentence "National Aeronautics and Space Administration" is substituted for "Department of Defense."

*Proposed*  
*Commerce Business Daily Announcement*  
*For*  
*PER/Preliminary Design*



**Architectural and Engineering (A/E) Services for the National Wind Tunnel Complex (NWTC) consisting of state-of-the-art wind tunnels with supporting systems and facilities.**

POC Henry L. Livas, Jr., Mail Stop 284, 804-864-3718, NASA Langley Research Center, Hampton, Virginia 23681-0001. The design services consist of preparing all necessary analyses, drawings, specifications, cost estimates, and schedules. The services will be phased as follows: combination Preliminary Engineering Report (PER) and preliminary design (30% final design), final design, engineering follow-up services during construction and activation. The estimated start date of the PER is April 1994 and the estimated construction completion date for the project is July 2002. The estimated range of the construction contract for the wind tunnel complex is between \$2.5 billion and \$3.0 billion. All deliverables (including drawings) shall be developed using an electronic database with the capability of electronic transmission to the Office of the Contracting Officer's Technical Representative (COTR).

The objective of the National Wind Tunnel program is to acquire wind tunnels which are responsive to the customer needs in support of aircraft development, are highly productive, are extremely reliable, are qualitatively superior to the world's best capabilities, and are energy efficient. The designs shall adequately control operational and ownership expenses to ensure minimum life cycle cost. The wind tunnel complex will perform aeronautical, engine, and acoustical developmental testing in the sub-sonic and transonic speed regimes. This complex shall be a stand-alone facility with all support systems including offices, model shops/preparation areas, auxiliary systems, etc. The complex includes a pressurized subsonic wind tunnel with a 20-ft by 24-ft test section, a pressurized transonic wind tunnel with an 11-ft by 15.5-ft test section, model buildup and preparation areas, supporting calibration facilities, ancillary supporting facilities, supporting auxiliary process systems, and supporting instrumentation and control systems. The Low Speed Wind Tunnel (LSWT) will have the following major features: closed circuit pressurized air wind tunnel with a removable plenum and test section, plenum and test section pressure/vacuum isolation system, tunnel total pressure range of 0.07 to 5 atmospheres, speed range of Mach 0.05 to 0.6, maximum total temperature of 130\_F, and superior flow and data quality. The LSWT will also operate in an open-jet mode at 1 atmosphere with an anechoic chamber surrounding the open jet. The Transonic Speed Wind Tunnel (TSWT) will have the following major features: closed circuit pressurized air wind tunnel with a removable plenum and test section, plenum and test section pressure/vacuum isolation system, tunnel total pressure range of 0.07 to 5 atmospheres, speed range of Mach 0.05 to 1.5, maximum total temperature of 130\_F, and superior flow and data quality. These tunnels will be highly productive, each one utilizing a removable plenum

and test section cart system for rapid model changes. The primary focus of this complex is to provide test facilities with high productivity and reliability, superior flow and data quality, and low cost per data point. The A/E services require the development of wind tunnel concepts and designs, integration of the wind tunnel designs with the necessary support systems and facilities, and the development of all analyses, drawings, specifications, and documentation in support of the designs while ensuring the productivity, flow quality, data quality, reliability, and cost requirements are met.

Consideration is extended to small and large business concerns. Consortiums, joint ventures, or firm/consultant arrangements are encouraged since significant A/E capacity and diversity of highly specialized engineering capabilities will be required to design this project. Joint ventures and firm/consultant arrangements will be evaluated based upon demonstrated interdependence of firms in providing a quality design effort and the capacity to follow through on all phases of the project. Responses should include SF 254 and 255 for all joint venture members and/or consultants and a composite SF 255 for the proposed team. Additional information (maximum 15 letter-sized sheets) responding to the selection factors below and relevant photographs or graphic examples (maximum of 10) will be permitted. No other information will be considered.

The NASA A/E selection board will apply the following criteria in order of importance:

- (1) Specialized experience and technical competence to accomplish wind tunnel designs and studies. Experience shall be demonstrated in the following areas:
  - a. WIND TUNNEL PERFORMANCE AND FLOW QUALITY
    - o Airline development; tunnel internals impacting test section flow quality such as conventional and rapid expansion diffusers, flow straightening and anti-turbulence components, contractions, turning vanes, acoustic noise suppression; subsonic nozzles and supersonic nozzles; tunnel drive systems (fan/compressor/motor assemblies); test sections (vented and unvented and with and without plenum evacuation systems, and open jet); model support systems; external and internal balance systems; gaseous injection and exhaust system components; and cooling coils.
    - o Integration of tunnel internal components with the tunnel pressure shell including attachments and penetrations
    - o Design and integration with tunnel systems of external process systems, data acquisition systems, and control systems.

b. PRODUCTIVITY

- o Model handling, preparation, and pre-test checkout systems
- o Calibration systems for tunnel process instrumentation and control systems, model instrumentation and control systems, and internal and external balances
- o Tunnel test section isolation and access systems
- o Data recording, reduction, evaluation, and archival systems
- o Automated tunnel operating and control systems, integrated control and data acquisition systems
- o Predictive maintenance systems including diagnostic systems which record trend data of critical tunnel components and tunnel ancillary support systems.

c. RELIABILITY/MAINTAINABILITY

- o Wind tunnel drive systems, model handling systems, model support systems, isolation systems
- o Automated, integrated process control and data acquisition systems
- o Air compressors, pumps, valves, and cooling systems

d. DATA QUALITY

- o Instrumentation/wiring systems
- o Data acquisition systems
- o Process control systems
- o Acoustic measurement systems
- o Flow quality
- o Background noise level

e. AUXILIARY SYSTEMS

- o High Pressure and Low Pressure Air systems, Hydraulic systems, Vacuum systems, and Cooling Water systems
  - o Utilities: Electrical, Water, and Natural Gas
- (2) Proven ability to develop accurate wind tunnel construction cost estimates and schedules including use of historical data. Ability to determine operation costs, maintenance costs, and life cycle costs.
- (3) Capacity/skill mix of the firm/team to accomplish aeronautical wind tunnel designs estimated to cost over \$25 million.
- (4) Ability to manage the design with regard to organization, achieving requirements, quality control, and schedule.
- (5) Past record of performance on aeronautical wind tunnel contracts with NASA, other Government agencies, foreign government agencies and private industry;
- (6) Familiarity with NASA and DOD, and private industrial installations that currently have wind tunnels;
- (7) Location of the firm (the A-E shall specify the location of the office where the work will be performed);
- (8) Volume of work previously awarded to the firm by NASA with the object of effecting an equitable distribution of NASA A-E contracts among qualified firms, including minority-owned firms and firms that have prior NASA contract.

Firms/teams will be evaluated on their ability to perform PER/preliminary design, final design, and engineering follow-up services during construction and activation in the event the project is funded through these phases. Following initial evaluation of qualifications and performance data, approximately four to six firms/teams will be interviewed. All firms to be interviewed will be required to submit a management plan for the design of the project in outline form in advance of actual interviews. If a strong firm/team emerges from interviews, the Contracting Officer may award the PER/preliminary design contract to a single design entity. Acceptable performance by the awardee may result in the subsequent award of the project's final design, and engineering follow-up services during construction and activation. However, the government incurs no obligation to award the aforementioned subsequent awards.

**National Wind Tunnel Complex**

**Proposed Commerce Business Daily Announcement for PER/Preliminary Design**

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As an alternative, the Contracting Officer may award multiple PER/preliminary design contracts (with identical Statements of Work). This scenario will result in the government's integration of the best aspects of all design concepts into a consolidated concept to be utilized in a subsequent final design solicitation. It should be noted that the government reserves the right to utilize all or any segments of design elements/components from any contract resulting from this solicitation. Large business A/E firms/teams shall submit an acceptable small business and small disadvantaged business subcontracting plan prior to award.

It is anticipated that the PER/preliminary design contract (or contracts) will be awarded in April 1994. Although funds are not currently available to accomplish the PER/preliminary design award, the necessary funding is expected to be available in the April 1994 time frame. However, Government assumes no legal liability in the event that funds are not appropriated to enable award of this contract.

Firms/teams are invited to respond by submitting SF 254 and SF 255 for firms/teams and consultants with a letter of interest identifying the project and solicitation number \_\_\_\_\_ to the office listed above within 30 calendar days of the date of this synopsis. Responses must be received NLT 4:30 p.m. of the 30 calendar days with publication day counting as the first day. This is not an RFP. However, firms/teams should provide detailed data (within aforementioned page limitations) on their capabilities.

**This contract is not set aside for Small Businesses.**

See Note 24. Provisions of Note 24 apply to this notice except that (a) in the sentence beginning "Selection of firms for negotiations," the fourth additional consideration listed is changed to read: "(4) past experience, if any, of the firm with respect to performance on contracts with NASA, other Government agencies, and private industry;" and (b) in the last sentence "National Aeronautics and Space Administration" is substituted for "Department of Defense."



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**ATTACHMENT 8.3**

**NATIONAL WIND TUNNEL COMPLEX**

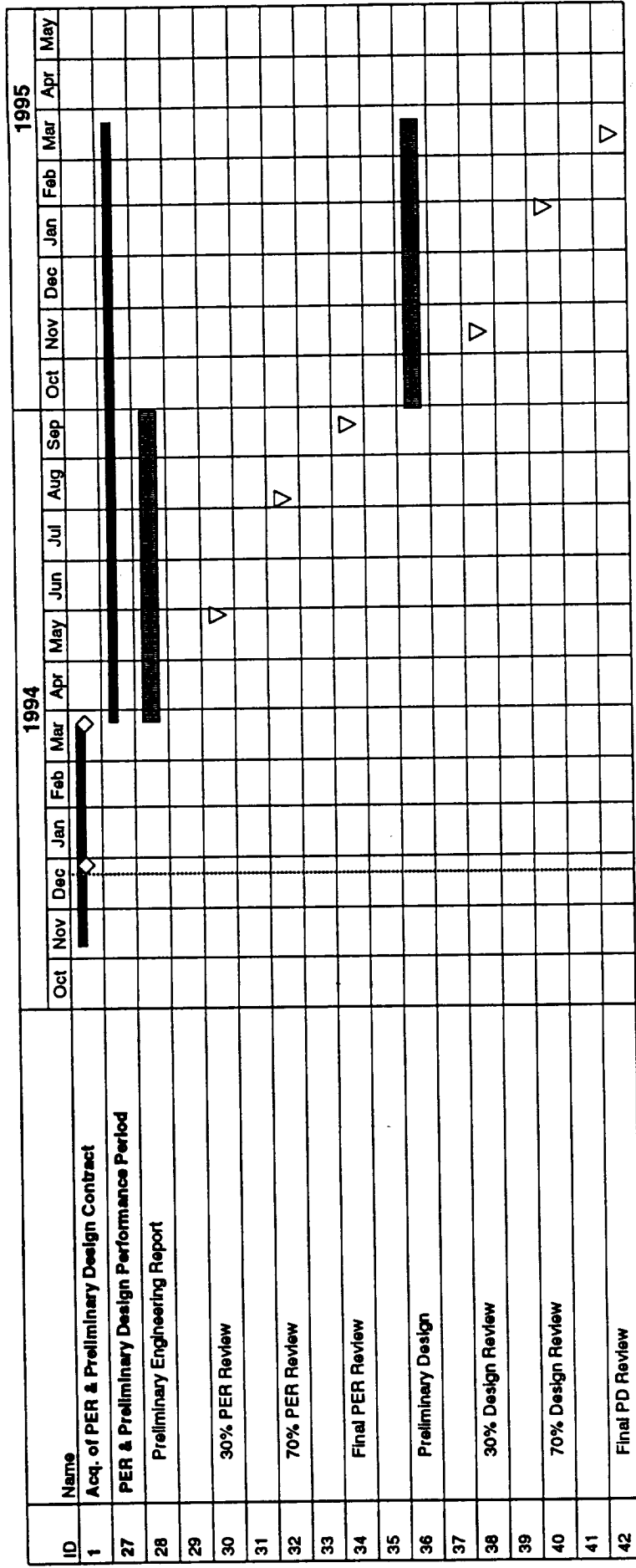
**STATEMENT OF WORK**

**FOR**

**PER/PRELIMINARY DESIGN**



# NATIONAL WIND TUNNEL COMPLEX PER/Preliminary Design Schedule





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UNITED STATES  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
LANGLEY RESEARCH CENTER  
HAMPTON, VIRGINIA

SPECIFICATIONS  
FOR  
PROFESSIONAL DESIGN SERVICES  
(ARCHITECT-ENGINEER)

PREPARATION OF A PRELIMINARY ENGINEERING REPORT  
AND  
PRELIMINARY DESIGN  
FOR  
NATIONAL WIND TUNNEL COMPLEX

LOCATED AT

\_\_\_\_\_, USA

SPECIFICATION NO.

DATE:



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SECTION 01021

SCOPE AND DESCRIPTION

PART 1 SCOPE

1.1 The work to be performed under these specifications shall include Architect-Engineer (A -E) services to prepare a Preliminary Engineering Report (PER) and develop the design to a Preliminary Design (30% complete stage) for the National Wind Tunnel Complex (NWTC).

1.2 The work shall include the furnishing of the A-E's office, all equipment, manpower, services, reproduction of material, and all operations necessary for or incidental to the preparation of the report(s), complete and ready for use and a Preliminary Design with drawings, analyses, cost estimates, design and construction schedules, checkout and calibration plans, and preliminary specifications utilizing the Government-furnished "SPECSINTACT" system.

PART 2 DESCRIPTION

2.1 In order to remain competitive in the world aviation market, the United States needs to have new subsonic and transonic wind-tunnels which are specifically design to provide capability beyond that which exists in this country's current wind tunnels for aeronautical, engine, and acoustical developmental testing. These two wind tunnels, The National Wind Tunnel Complex, shall provide increased production capacity, increased Reynolds number capability, and high data quality at affordable user cost. These wind tunnels are continuous operating, closed loop facilities with high productivity features such as a multiple test-section cart system for each tunnel. The Low Speed Wind Tunnel (LSWT) shall have a 20 foot X 24 foot test section while the Transonic Speed Wind Tunnel (TSWT) shall have an 11 foot X 15.5 foot test section with both tunnels being operational to five (5) atmospheres total pressure. In addition to the two wind tunnels, auxiliary process systems, test preparation and control buildings, drive / compressors / vacuum station building, engineering offices, support infrastructure, controls, instrumentation, and data

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acquisition systems shall be provided to support the Complex as self sufficient facilities. The Complex will be built on a "green field" site with utilities provided at the boundary to the site.

- 2.2 The facilities shall be laid out, powered, lighted, heated, air conditioned, ventilated, plumbed and finished off in a manner conducive to the function intended and at a cost within the funding limitation.
- 2.3 The construction details and materials selected shall be influenced by their suitability to the environment to which they are exposed, durability, and reduction in the cost of maintenance and ownership over a 50 year operating life.
- 2.4 Special consideration shall be given to areas using hazardous chemical, toxic and explosive materials, to give positive assurance of design compatibility offering a safe working area that is non-polluting to the environment.
- 2.5 A copy of the NASA Guide for Preparing a NASA Preliminary Engineering Report is appended hereto and is hereby made a part of these specifications. The final report(s) shall be prepared in compliance with these instructions and additional requirements as contained in these specifications.

## PART 3 SCHEDULE

- 3.1 The PER shall be delivered complete and in final form within 189 calendar days after award of contract.
- 3.2 The Preliminary Design shall be completed, including incorporating government comments, and delivered within 364 calendar days after award of contract.
- 3.3 The PER report and design drawings, calculation, specifications, and all backup data shall be delivered to the office of the Contracting Officer, at Mail Stop 284.
- 3.4 A Review Board will be convened at the government site to hear oral presentation of the PER and Preliminary Design.
- 3.4.1 Three oral reviews shall be presented on the PER, a 30% review within 65 calendar days, a 70% review within 135 calendar days and a final review within 180 calendar days of contract award.

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- 3.4.2 Three oral reviews shall be presented for the Preliminary Design, a 30% review within 235 calendar days, a 70% review within 310 calendar days, and a final review within 354 calendar days after contract award.

**PART 4 ORAL REVIEWS**

- 4.1 The A-E shall furnish qualified representatives knowledgeable in all applicable engineering disciplines to prepare and present material for presentation at the Oral Reviews. A preliminary copies of slides to be presented at the reviews shall be furnished to the government 15 calendar days prior to the review. A rehearsal will be held at the Government site approximately two days prior to the formal presentation. The A-E shall have representatives present at the rehearsals and at the Oral Reviews.
- 4.2 The PER has a three-fold purpose: first to develop a project which embodies sound engineering and economical methods of fulfilling the functional requirements; second, to provide data, including detailed cost estimates, to support budget submittals; and third, to be the basis of preparing final plans, specifications, exterior architectural treatment, and selecting materials and colors, all in conformance with the specified guidelines. The purpose of the Oral Reviews are to provide a third party review to verify that the objectives are met.
- 4.3 The Preliminary Design (30% design complete) further develops concepts proposed in the PER. The intent is to advance the design maturity to a point where technical objective, cost and schedule can be more accurately assessed. The purpose of the Preliminary Design Reviews is to provide a third party review to verify the design approach relative to the intended use of the facility; to verify that the design is within available funding; and to assure project completion within the established schedule.
- 4.4 The A-E shall provide the applicable information in the form of viewgraphs or slides, necessary for the reviews. Projector equipment will be provided by the Government. Two copies of all material to be presented shall be furnished to the Contracting Officer, at Mail Stop 284, at least 10 calendar days prior to the date set for the review. The Review Panel will be appointed by the Government and will direct its comments and recommendations to the Government Technical Representative, who will initiate all contractual action through the Contracting Officer.

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**PART 5      PROJECT REQUIREMENTS**

- 5.1      The performance requirements for the National Wind Tunnel Complex are defined in the Requirements Document, Dated \_\_\_\_\_

**PART 6      DRAWINGS AND INFORMATION FURNISHED BY THE GOVERNMENT**

- 6.1      The Government will make available to the A - E the results of special studies conducted by the government or its agent on various aspects of this project as these studies are completed. However, the ultimate design shall be the responsibility of the A-E and shall be guided by the Facilities Engineering Handbook - NBH 7320.1B.

**PART 7      LONG LEAD ITEMS**

- 7.1      The A-E shall identify items that will require early procurement in order to meet the project schedule such as the tunnel pressure shells and tunnel compressor systems. The A-E shall provide contract drawings and specification complete and ready of use for the procurement for the long lead items. All interfaces including loads shall be provided.

**PART 7      PROGRESS REPORTS**

- 7.1      The A-E shall submit four copies of all drawings, cost estimates, applicable design data, vendor quotations and computations generated or updated during the reporting period for Government review at 4 week intervals following award of the contract. Prints of the work "as is" will serve the purpose. These prints shall be clearly dated and marked "Progress Prints". Each progress report shall be accompanied by an updated cost estimate review and a written report that verifies the project design is technically sound, on schedule, and within the allotted construction funding specified in Paragraph 8.1.

**PART 8      ESTIMATED COST**

- 8.1      The Budget Construction Estimated Cost for the project is \$2.87 billion including the Government contingency, cost rise, and construction management.

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- 8.2 The A-E shall prepare his design, including construction contract drawings and specifications, to bring the contract cost of constructing the project within this authorization. If, at any time, during the preparation of plans and specifications, the A-E finds that the requirements for the project appear inconsistent with the funds available, the A-E shall promptly refer such findings to the Contracting Officer for action.

Part 9 Coordination

- 9.1 The Government reserves the right to have representatives continually review the work effort as the design progresses. The A-E shall cooperate fully and make sufficient information available to evaluate the design approach.
- 9.2 The A-E shall provide basic office space, furniture, and telephones for up to 6 government representatives at the A-E site during the PER and Preliminary Design performance period.



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SECTION 01022

GENERAL REQUIREMENTS

**PART 1** This section of the specifications outlines the general requirements to be met by the A-E for this report.

**PART 2** Design Criteria:

**2.1** Design criteria for the preliminary design to be accomplished under these specifications shall utilize, to the maximum possible extent, the NASA Facilities Engineering Handbook, NHB 7230.1B. It shall also be in accordance with the applicable provisions of the latest standards, codes, and requirements of the following organizations:

American National Standards Institute (ANSI)  
American Institute of Steel Construction (AISC)  
American Concrete Institute (ACI)  
American Association of State Highway Officials (AASHO)  
American Society for Testing and Materials (ASTM)  
American Welding Society (AWS)  
American Society of Mechanical Engineers (ASME)  
American Society of Heating, Refrigeration and  
Air Conditioning Engineers (ASHRAE) - Notably ASHRAE 90-80  
Building Officials and Code Administrators, International, Inc.  
(BOCA) Codes  
The Institute of Electrical and Electronics  
Engineers Inc. (IEEE)  
National Electrical Code (NEC)  
National Electrical Manufacturers Association (NEMA)  
Insulated Power Cable Engineers Association (IPCEA)  
Illuminating Engineering Society (IES)  
National Board of Fire Underwriters (NBFU)  
National Electrical Safety Code (NESC)  
National Lumber Manufacturers Association (NLMA)

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Aerospace Industries Association of America, Inc. (ARTC-41)  
Aluminum Association of America  
National Fire Protection Association, Life Safety Code  
Standard Practice for the Fire Protection of Essential  
Equipment Operations RP-1 U. S. Department of Commerce  
NASA Safety Standard for the Fire Protection of Essential  
Electronic Operations (NSS/FS 1740.3)  
Occupational Safety and Health Act, Public Law 91-596  
Sheetmetal and Air Conditioning Contractors National  
Association, Inc. (SMACNA) Duct Manual  
Carrier System Design Manual

- 2.2 The design policies, criteria, and standards outlined in NASA Facilities Engineering Handbook (NHB 7320.1B) shall be followed in the preparation of the PER. Deviations required to meet specific conditions or problems shall be identified in the PER and the rationale, in outline form, to support each deviation shall be provided. When materials or systems are selected which are not in general usage, a comparative engineering, and economic analysis of advantages and disadvantages shall be provided.
- 2.3 The design shall render the best engineered project(s) considering initial cost and maintenance costs that will satisfy the requirements and will withstand an analysis based on cost effectiveness. "Life Cycle Costing" techniques shall be fully utilized and shall be based on permanent construction.
- 2.4 In the preparation of a Preliminary Engineering Report, planning and design criteria to be issued by NASA shall be utilized to the greatest possible extent. The A-E is encouraged to develop the most economical schemes for accomplishing the desired performance with high reliability and with minimum cost.. Within the scope of NASA policy on planning and design, the A-E will be allowed the maximum latitude in creative thinking, new concepts, and use of new materials consistent with NASA criteria.
- 2.5 Although specific conformity to nationally recognized building codes is not required, such codes should be used as guidelines for design criteria not otherwise provided in these specifications.
- 2.6 Conformity to nationally recognized safety codes, as minimum standards, is required including Public Law 91-596, Occupational Safety and Health Act.

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- 2.7 The A-E's design shall give due attention to acoustics so that work areas will not be exposed to undesirable noise levels from equipment provided under this design.
- 2.8 The A-E shall incorporate applicable provisions of the U.S. Architectural and Transportation Barrier's Compliance Board's "Minimum Guidelines and Requirements for Accessible Design".

## PART 3 GENERAL REQUIREMENTS

- 3.1 Section 1 of the PER entitled "Requirement Statement" will be furnished by the Government and shall be inserted verbatim in the report.
- 3.2 The A-E shall examine alternate solutions to problems arising in the design. A brief description of the alternate solutions considered and the reasons for rejection, or a statement that no alternate solutions were considered and the reasons shall be included, as discussed in Section II of "Guide for Preparing NASA Preliminary Engineering Reports (PER)."
- 3.3 Seismic criteria, snow and wind loadings, and temperature shall be as specified for design at **the Government Site**. Construction materials shall be of type similar to those presently in use at **the Government Site** and particularly in the immediate area of the facility. Variation should be avoided. Where deviations are necessary, the A-E shall provide explanation and reasons therefor.
- 3.4 The enclosed "Guide for Preparing NASA Preliminary Engineering Reports" - states that the engineering estimate shall be based on current prices. If bids were submitted at the time the estimate was prepared, the amount of the estimate should approximate the anticipated low bid from a construction contractor. The budget estimate is arrived at by adding percentages to cover construction contingencies, cost-rise, and construction management services.
- 3.5 The engineering estimate required in Section III of the enclosed "Guide for Preparing NASA Preliminary Engineering Reports" shall be detailed on a form similar to Figure 1. The engineering estimate and the budget estimate shall then be reported in the format shown in the "Guide." The contingency factor shall be 10 percent, the cost-rise factor shall be 3.5 percent per year, projected to mid-point of construction and 8 percent shall be included for construction management services. The estimated date of start of

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construction is March 1997 for long lead items and February 1998 for general construction.

- 3.6 The cost estimate(s) derived in preparing the PER will be reviewed by the Contracting Officer during the Government-Architect-Engineer conferences, and prior to being summarized on NASA Form 1510, shown in Section 01023.
- 3.7 Cost estimates shall be reasonable and adequate. Any special features, that increase or decrease costs appreciably from normal or basic construction costs, shall be explained fully. A cost risk factor shall be assign to each element of the work to reflect uncertainty in the estimate. A form similar to Figure 1 shall be completed in detail for the project. These estimates shall show quantity, unit pricing and total price for each item. The cost estimate shall be maintained on an electronic spread sheet and shall utilize the Work Breakdown Structure established for the project.
- 3.8 The Government will make all reproductions of the report(s). The A-E shall furnish one original and two copies of all typewritten material for the report(s). The original shall be on a vellum reproducible or a good grade of clear white bond. The original report shall be prepared with a "word processor". The A-E shall furnish copy of the original storage tapes or disc to the Government. These tapes or disc will be retained by the Government and may revised if necessary. Drawings shall be on 22-inch by 34-inch mylar tracing sheets. The A-E will not be required to reproduce or append these drawings to the report(s). Drafting shall be of quality suitable for photographically reproducing these drawings in one-half size by the offset process. Differentiation on drawings shall not be by color or shading but rather by cross-hatching to facilitate the reproduction.
- 3.9 The A-E shall exercise care to ensure that each preliminary design provides for a complete project. In the event it is necessary to rely on having work accomplished by means not included in this project, then such work shall be carefully noted. The A-E shall use the furnished Description of Project(s) Section 01021, only as a guide and the A-E shall not limit himself/herself to the Government's description. The A-E will be expected to use field investigation and professional expertise to establish the final documents.
- 3.10 The A-E shall take all action necessary to obtain the data upon which to develop the design of the project(s), such as visiting the

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site(s), holding conferences, and any other action deemed necessary for the completion of the work.

- 3.11 The A-E shall exercise every safeguard to prevent persons other than those with the need-to-know from obtaining knowledge of information on the project, and shall exercise every caution to prevent unnecessary disclosures regarding the project.
- 3.12 All electrical and mechanical equipment shall be installed no less than 9-feet above mean sea level.
- 3.13 The A-E shall make site surveys and investigations as required and may take additional soil borings if he considers it necessary to design the projects.

3.14  
PART 4

PRELIMINARY CONSTRUCTION DRAWINGS AND SPECIFICATIONS

- 4.1 The A-E shall provide preliminary construction drawings and specifications covering the various trades and detailed requirements of the work. Performance specification shall be provided for those items to be procured by performance specifications. Construction specification shall utilize SPECSINTACT, the Government's computerized system for organized storage, selective retrieval, and rapid print-out of standard construction specifications.
  - 4.1.1 Detailed instructions in the use of SPECSINTACT will be furnished to the A-E, including procedures for selecting appropriate text, changing existing text and incorporating additional text.
  - 4.1.2 All computer operations for printing the specifications will be accomplished by the Government.
- 4.2 Construction drawings shall include the following:
  - 4.2.1 Cover Sheet - with name and number of facility, project title, and list of drawings indicating NASA numbers, A-E numbers and titles of drawings.
  - 4.2.2 A-E shall use NASA Graphics Standards on drawings as follows:  
  
New Construction - Solid Dark Lines  
Existing Construction - Dashed Light Lines

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To Be Removed - Dotted Lines

Section (Detail) Symbol

Section (Detail) Number

. I . Shown On

Cut On

### 4.2.3 Civil Drawings

4.2.3.1 Plot plan with contours, grades, and finished earthwork if needed to define the work.

4.2.3.2 Plot plan with roads, drives, walks, limits of construction and utilities (existing and new) (1 inch equals 30 feet).

4.2.3.3 Plot plan with soil survey information (if required).

### 4.2.4 Architectural Drawings

4.2.4.1 Plans, elevations and complete construction details.

4.2.4.2 Complete Color Schedules for all exteriors and interiors.

4.2.4.3 Ceiling plan showing layout of acoustical grid system (if any), lighting fixtures and mechanical fixtures.

4.2.4.4 Foundation and structural plans and details with all loads forming the basis of design on these drawings.

4.2.4.5 Column, slab, joist, beam, and truss schedules (if required).

4.2.5.6 Concrete reinforcing steel details (if required).

4.2.4.7 Necessary details of special or unusual features.

### 4.2.5 Mechanical

4.2.5.1 Layouts and details of mechanical equipment and systems (See Section 01025).

### 4.2.6 Electrical

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- 4.2.6.1      Layouts and details of electrical equipment systems (See Section 01024).
- 4.4.7          Process Systems
  - 4.4.7.1      Layout and details of process systems ( See Section 01027)
- 4.3           Drawings shall match the specification sections; i.e., reinforcing steel shall be shown on concrete drawings; electrical work on electrical drawings, etc. The nomenclature used on contract drawings shall agree with that used in specifications. To prevent the possibility of interference between structural and/or architectural elements and adjacent utilities, utility locations, where necessary, shall be indicated on structural and architectural drawings.
- 4.4           Drawings shall be executed on 22 inch by 34 inch imprinted mylar drafting film. Drafting shall be done by such methods and be of such quality workmanship as to permit the making of legible reproductions and revisions of the drawings without impairing their integrity. Each sheet of drafting film will have a **Government** title block, in which, in an approved manner, the A-E shall enter the name of his firm with spaces for his designer, draftsman, checker, engineer and signature of approving principal, in the blank space of the title block near the midsection of the drawing. Drafting and lettering shall be of such size and density that after reduction to half size work is fully legible. Copies of the computer disks shall be transmitted along with the original mylar drawings, specifications and cost estimate at design completion prior to final payment
- 4.5           All references in this document to A-E developed drawings shall include hard copy plots and data files from a Computer Aided Design and Drafting (CADD) program. Aforementioned drawing files shall be totally compatible for all parameters with AutoCAD Ver. 12 (Autodesk Inc., CADD Software) and provided in drawing file format (.DWG) on 5.25"/1.2 Mb or 3.5"/1.44 Mb disks for DOS application.

Development of Electronic Database Drawings shall be governed by generally accepted industry CADD operation procedures describing proper CADD drafting techniques including the following:

  - o           All drawing practices and conventions shall adhere to standards defined in DOD-STD-100 and DOD-D-1000

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- o All extraneous layers, line types, blocks, and styles not necessary shall be purged; layer 0 not to be used.
- o Lines shall be continuous, not segmented, with only special application of poly line or non-standard width lines accepted.
- o Drawings shall be layered, colored, and text styled per LaRC standard format layering schemes.
- o Deviations from aforementioned procedures must be submitted for approval.

**PART 5     TRAVEL**

- 5.1     The A-E shall arrange to meet with Government personnel involved in the projects prior to the start of the PER and Preliminary Design, to discuss the projects, and to settle any questions, changes, or controversies before actual work is begun. At this time the A-E will be furnished additional information if needed.
- 5.2     In order to maintain technical liaison, the A-E shall make all necessary arrangements for conducting Government-A-E conferences at the Government Site.

**PART 6     ENVIRONMENTAL POLLUTION ABATEMENT**

- 6.1     The PER(s) shall contain separate items of cost for providing required measures for compliance with applicable environmental pollution standards. Applicable pollution control standards means the same Federal, state, or local substantive, procedural and other requirements that would apply to a private person.

**PART 7     DESIGN ENERGY BUDGET**

- 7.1     The A-E shall establish a design energy budget for the facility. This budget shall be expressed in terms of KWH for electrical energy usages and thermal units for natural gas and shall be an estimate of the total energy that will be required to operate the facility within the design conditions on an annual basis. The A-E shall give special attention to the design to minimize energy utilization and facilitate energy management for operation of the facility.

NOTE: TPE to add cost estimate form

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SECTION 01023

DETAIL REQUIREMENTS - ARCHITECTURAL, STRUCTURAL AND CIVIL

PART 1 SCOPE

- 1.1 This section outlines the detailed requirements to be met by the A-E in the architectural, structural and civil design.

PART 2 CODES

- 2.1 Although specific conformity to nationally recognized building codes is not required, such codes should be used as guidelines for design criteria not otherwise provided in this specification.
- 2.2 Conformity to nationally recognized safety codes as minimum standards is required.

PART 3 STRUCTURAL AND CIVIL DESIGN

- 3.1 Extension, modification, or relocation of utilities at project site(s) shall be included in the report(s), including all necessary storm drainage, parking, approach drives, grading, and any other site development work.
- 3.2 Site preparation shall include filling, grading, drainage, top soiling, seeding, and other plantings.
- 3.3 Insofar as possible, the plans for this facility shall be laid out so that the demolition of existing facilities, utilities or pavement areas will not be required.
- 3.3 Design live loads shall be as follows:
- 3.3.1 Offices, corridors, stairways, landings,

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- toilets. . . . . 100 psf or a  
2000 lb. concentrated  
load\*.
- 3.3.2 Small equipment laboratories, very  
light shops. (This category is  
intermediate between offices and  
conventional, relatively heavy shops) . 150 psf or a  
2000 lb. concentrated  
load\*.
- 3.3.3 Mechanical equipment rooms, slabs, on  
grade exposed to vehicle traffic, shops  
and heavy equipment areas . . . . . 250 psf or a  
5000 lb. concentrated  
load\*.
- 3.3.4 Floor loading capacities for special purpose areas which support  
tunnel components shall be design to support those components
- 3.3.5 Roofs (normal flat roof). . . . . 30 psf
- 3.3.6 Roofs (exposed to frequent  
setups and foot traffic). . . . . 60 psf
- 3.3.7 Vaults - storerooms . . . . . 250 psf
- 3.3.8 Sidewalks . . . . . 4 in. min./250 psf
- 3.3.9 Roads, drives, utility tunnel tops  
and manhole tops . . . . . H-20
- 3.3.10 Minimum windload (ANSI A58.1). . . . . 30 psf below 90 feet  
120 MPH peak velocity  
above 90 feet
- \*Concentrated loads assume to be on area 2-1/2 feet x 2-1/2 feet.  
Use loading which gives most severe stress (bending, shear, axial,  
or deflection).
- 3.4 Since the construction site has not been made, the A-E shall make  
reasonable assumptions for a generic site condition and shall  
clearly document these assumptions.

## PART 4 ARCHITECTURAL DESIGN

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- 4.1 Interior finishes shall be selected based on their aesthetic and acoustic characteristics as well as their functionality.
- 4.2 The building exterior fenestration shall be consistent with the Master Plan and construction of the adjacent buildings. Windows shall be insulated bronze glass with operable sash (or Hopper vents), and have a thermal break.
- 4.3 Restrooms shall have ceramic tile walls and floors.
- 4.4 Life safety codes and flame spread ratings shall be adhered to.
- 4.5 The A-E shall incorporate applicable provisions of the U.S. Architectural and Transportation Barrier's Compliance Board's "Minimum Guidelines and Requirements for Accessible Design."



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SECTION 01024

DETAIL REQUIREMENTS - ELECTRICAL

Part 1 Scope

- 1.1 This section outlines the general electrical requirements to be utilized by the A-E. The following electrical items, as a minimum, shall be included: power distribution, lighting, communications, security, and controls.

Part 2 Design Standards

- 2.1 The design shall conform to the applicable standards listed in Section 01022.

Part 3 Primary Power Distribution System

- 3.1 Provide a primary electrical power distribution system for the operation of the National Wind Tunnel Complex (NWTC) including the related switching, power conditioning, harmonic filtering, and voltage transformation equipment to enable the wind tunnel complex to utilize the power obtained from the utility company. Ensure that the appropriate power factor is maintained and that the generated harmonics are within acceptable guidelines. Provide documentation of the harmonic and power factor analysis during the preliminary design. Provide drawings showing the anticipated ratings, physical size, and location of the power distribution equipment. Provide documentation on the estimated levels of power required.
- 3.2 Depending upon voltage available from the electrical utility company, the delivered primary voltage could range from 115 kV to 230 kV. For the development of the PER and for the start of the preliminary design, 138 kV shall be used as the delivered primary voltage. After completion of site selection, negotiations will be held with the utility company to determine the exact voltage that will be delivered. It is anticipated that the primary power will be delivered to one main substation and two wind tunnel drive substations (one substation each for the Low Speed Wind Tunnel and the Transonic Wind Tunnel). Medium and low voltage substations shall provide

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power at 4.16 kV and 480 volts. Power shall be distributed between the substations and equipment by power cables/busses in cable tunnels and/or ductbanks. The substations shall be strategically located to keep the secondary cable/bus systems to a minimum. Security lighting and security fences shall be provided for the substations.

3.3 During the developed of the PER and the preparation of the preliminary design, the A-E shall determine the power needed for the operation of the NWTC. Each time that changes are made in the design that results in a change in the estimated power needed, the A-E shall provide documentation to the project office. The currently estimated levels of power are:

- o Total connected load: 510 MW
- o Peak demand load: 400 MW
- o Average demand load: 300 MW
- o Average monthly electrical energy usage: 55 million KWH
- o Average monthly power factor: 95%
- o Voltage from utility company: 138 kV
- o Short circuit capacity: 10,000 MVA
- o Ramp rate: 2 MW per second

Part 4 Secondary Power Distribution System

4.1 Provide a secondary power distribution system including panelboards, motor control centers, switchboards, and similar power distribution equipment. Provide raceway and feeder systems to distribute the power to the equipment. All wiring shall be installed in raceways.

4.2 Panelboards shall be provided with 1/3 spare breakers. Appropriate spare devices shall also be included in the other distribution equipment.

Part 5 Grounding

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- 5.1 Provide an electrical grounding system to meet the National Electric Code, local codes, and utility company requirements. All enclosures for electrical equipment shall be connected to the grounding systems with appropriately sized copper conductors.

Part 6 Exterior Lighting Systems

- 6.1 Provide general area lighting in accordance with the Illuminating Society of North America standards for all exterior areas of the complex. Lighting for all outside support systems requiring 24 hour maintenance and/or operation shall have enhanced illumination levels. In areas where safety and/or security are important, the lighting shall be supplied by an uninterruptible power source or shall automatically transfer to a diesel powered generator.

Part 7 Interior Lighting Systems

- 7.1 Provide an energy efficient lighting system for the interior areas of the NWTC. As a general rule, all office areas, control rooms, data acquisition rooms, and similar areas shall utilize fluorescent lighting fixtures with electronic ballast. As a general rule, shops and other high bay areas shall utilize HID lighting fixtures.

- 7.2 The lighting system shall be distributed from 277/480 volt 120/208 volt panelboards.

- 7.3 Lighting levels shall be noted on preliminary drawings and shall be as follows:

Offices and similar areas	70 foot-candles
Shops	50 foot-candles
Corridors	20 foot-candles
Little used areas	Dependent upon area

Part 8 Communications Systems

- 8.1 Provide telephone and intercom system throughout the complex. Provide remote video/audio in the yard and facility areas where safety and/or security are required and where the efficiency of operations will be improved. The telephone system shall include telephone equipment rooms, cabinets, raceway systems, and outlet boxes. For the purpose of the preparing the PER and for the start of the preliminary design, it should be assumed that the telephone cables and equipment will be provided by the local telephone company. After site selection is finalized, a final

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determination will be made as to whether the local telephone company will provide the cables and equipment.

Part 9 Security Systems

- 9.1 Provide security systems including fencing, gates, security lighting, remote operated close circuit television (CCTV), alarms, and separate security communications for the NWTC.

Part 10 Cathodic Protection

- 10.1 Provide a cathodic protection system to reduce the corrosion of electrical components and equipment.

Part 11 Lightning Protection

- 11.1 Provide a lightning protection system to protect the electrical equipment from lightning strikes.

Part 12 Freeze Protection

- 12.1 Provide a freeze protection system for the equipment that located where freezing may occur.

Part 13 Environmental Monitoring

- 13.1 Provide a system to monitor weather, noise, emissions, effluents, or similar environmental factors for the NWTC.

Part 14 DC Power for Instrumentation

- 14.1 Provide a DC power system for instrumentation.

Part 15 Motors and controls

- 15.1 The voltage ratings given in the table below shall be used for motors.

<u>Horsepower</u>	<u>Phase(s)</u>	<u>Voltage Rating</u>
1/2 or less	1	120
1/2 or less	3	230/460 dual
over 1/2 through 25	3	230/460 dual
over 25 through 100	3	230/460

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over 100

3

to be determined  
based on hp rating

**15.2** As a general rule, reduced voltage control circuits shall be provided for all equipment operating on voltages in excess of 120 volts to ground.

## Part 16 Fire Detection and Alarm System

**16.1** Provide state of the art fire detection and alarm system(s) for the NWTC. Provide product-of-combustion detectors, heat detectors, and similar detection devices depending upon the location and facility usage. Provide an alarm panel for each facility. Provide audio/visual alarm devices in all interior areas and in appropriate exterior areas. Provide a central graphic annunciator panel for each major building or facility. Connect the alarm panels via telephone lines to the facility fire station. If the site chosen does not have an existing central fire station, it will be necessary to provide a new fire annunciator system in the new fire station.

## Part 17 Preliminary Design Drawings

**17.1** For the preliminary design, the A-E shall prepare separate electrical drawings which shall be clear and concise, with notes, references, details, and other information necessary for a complete installation. Except for the electrical site plans, the scale shall not be not be smaller than 1/8 inch per foot. The electrical site plans may be drawn to a scale of 1 inch equals 30 feet. Larger scales shall be used where necessary to improve interpretation. Separate drawing presentations (not necessarily separate drawing sheets) shall be prepared for each system, such as power, lighting, fire alarm, communications, controls, etc. ANSI symbols shall be used throughout all electrical drawings. The following drawings shall be included.

- o Complete single line power diagrams.
- o Riser diagrams.
- o Feeder schedules.
- o General layouts and location plans for lighting, fire, alarm, communication, security, receptacles, lightning protection, cathodic protection, and power systems.

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- o General layout and locations plans with approximate dimensions of major pieces of equipment for substations, switch gear, duct bank and cable tunnels, motor controls equipment.

#### Part 18 Preliminary Electrical Specifications

- 18.1 For the preliminary design, the A-E shall prepare preliminary specifications covering the major electrical components including substations, auxiliary motor controls, primary and secondary power cabling systems, raceways, main drive motor controllers, fire alarms and annunciator systems, cathodic protection systems, security systems, lightning protection systems, communications systems, freeze protection, environmental monitoring systems, motors, and instrumentation power system.

#### Part 18 Preliminary Design Calculations and Analysis

- 18.1 For the preliminary design, the A-E shall prepare sufficient calculations and analysis to permit determining the ratings of the electrical equipment. As a minimum, these calculations shall include connected and demand loads, cable and bus ratings, and short circuit and load analysis.

#### Part 19 Spare Capacity

- 18.1 For the preliminary design, the A-E shall provide equipment such as panelboards, auxiliary motor control centers, and switchboards with approximately 1/3 spare capacity and devices:

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SECTION 01025

DETAIL REQUIREMENTS - INSTITUTIONAL MECHANICAL

Part 1      Scope

- 1.1            This section outlines the general institutional mechanical requirements to be utilized by the A-E.

Part 2      Design Standards

- 2.1            The design shall conform to the applicable standards listed in Section 01022.

Part 3      Water Supply and Treatment System

- 3.1            Provide a potable water system and provide a cooling water system for the main drives and auxiliary equipment.
- 3.2            The source of potable water is dependent upon the site selected. During the preparation of the PER, the A-E shall investigate alternate sources of potable water and recommend a source to be used. One alternate to be investigated is the use of well water with pumps, piping, and storage tanks. A second alternative to be investigated is the use of a municipal water source, piping, and storage tanks. The chosen alternative shall be further developed during the preliminary design.
- 3.3            The source of cooling water is dependent upon the site selected. During the preparation of the PER, the A-E shall investigate alternate methods of cooling the main drives and auxiliary equipment and recommend a method to be used. One alternative to be investigated is to use a river intake and treatment system for the water source as the primary source of cooling water. Another alternative to be investigated is the use of a municipal water system as the source of cooling tower makeup water. The chosen alternative shall be further developed during the preliminary design.

Part 4      Sanitary Waste Water Collection and Treatment System

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- 4.1 Provide a sanitary waste water collection system and treatment system. The method of waste water treatment is dependent upon the site selected. During the preparation of the PER, the A-E shall investigate alternate methods of waste water treatment and recommend a method to be used. If the site selected has a regional or local sewage treatment facility of sufficient capacity, the sewage shall be collected and pumped to this existing facility for treatment and discharge. If an existing treatment plant is not available, a dedicated treatment plant shall be constructed. The chosen alternative shall be further developed during the preliminary design.

#### Part 5 Natural Gas System

- 5.1 Provide a natural gas distribution system including piping, pressure reducing station, metering, and valves to the facilities. Include in the PER, the anticipated maximum flow rate and annual usage of natural gas for the NWTC.

#### Part 6 Fire Protection System

- 6.1 Provide water source, valves, piping, fire hydrants, etc. for the general fire suppression system. During the preparation of the PER, the A-E shall investigate alternate methods of providing water for fire protection and recommend a method to be used. The chosen alternative shall be further developed during the preliminary design.

- 6.2 Provide wet pipe sprinkler systems for all shops, laboratories, data acquisition rooms, and computer rooms. Include recommendations on other areas/facilities that should be provided with a fire suppression system.

#### Part 7 Compressed Air System

- 7.1 Provide a service air system including compressors, storage vessels, piping, valves, and controls for the NWTC.

#### Part 8 Plumbing

- 8.1 Provide a complete restroom facility system. The number of fixtures in the restrooms shall be based on the BOCA Plumbing Code. All plumbing fixtures, including water closets, shall be wall hung. Drinking fountains shall include both hot and chilled water

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features. Make provisions for the handicapped as required by the BOCA Plumbing Code.

Part 9 Air Conditioning

9.1 Provide a complete heating, air conditioning, and ventilation (HVAC) system for year around occupancy and use of the NWTC. The selection of the HVAC system shall be based on a study of the requirements, extent of control required, humidity requirements, nature of occupancy, appearance, building structures and other factors peculiar to the NWTC. Special consideration shall be given to optimize energy conservation. The A-E shall verbally present and describe his proposal to project personnel. This presentation shall include single line sketches and flow diagrams, preliminary design calculations, cost estimates, system advantages, and system disadvantages. The design calculations shall be by the block load method. Calculation factors shall be obtained from the ASHRAE Guides. Calculations shall be made to determine the time of day and year which will require maximum cooling.

9.2 The final outdoor design conditions is dependent upon the site selected. For the preparation of the PER and the start of the preliminary design, the A-E shall utilize the design conditions listed below. After site selection is made, the A-E will be advised of any changes to the design conditions.

Outside conditions

Summer 95 degrees F dry bulb (DB), 78 degrees wet bulb (WB)

Winter 10 degrees DB at 0 grains of moisture per pound of dry air

Indoor conditions: Computer rooms and data acquisition rooms

Summer/winter 70 plus or minus 2 degrees F at 50% RH plus or minus 5%

Indoor conditions: Offices, conference rooms, shops, etc.

Summer 76 degrees F DB plus or minus 2 degrees at 35% to 60% relative humidity (RH)

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Winter 76 degrees F DB plus or minus 2  
degrees at 35% to 60% RH

## Noise criteria

General offices	40 N. C.
Conference Rooms	30 N. C.
Private Offices	35 N. C.

## Ventilation Criteria

General areas	15 cfm per person
Restroom exhaust	2 cfm/sq. ft.

## Controls

### Individual room control

- 9.3 As far as practical, all air conditioning shall be installed in central utility room(s). The equipment room(s) shall be designed to make maintenance easy and simple. Equipment rooms shall be provided with access for moving equipment in and out. The A-E shall detail the layout of the equipment room showing the proposed equipment and noting the areas that will be reserved for maintenance and/or removing of components.
- 9.4 Where practical, avoid the use of roof mounted equipment.
- 9.5 Where practical, avoid the use of electricity as the prime energy source for heating.

## Part 10 Preliminary Design Drawings

- 10.1 For the preliminary design, the A-E shall prepare separate mechanical drawings which shall be clear and concise, with notes, references, details, and other information necessary for a complete installation. Except for the mechanical site plans, the scale shall not be smaller than 1/8 inch per foot. Larger scales shall be used where necessary to improve interpretation. The mechanical site plans may be drawn to a scale of 1 inch equals 30 feet. Separate drawing presentations (not necessarily separate drawing sheets) shall be prepared for the following:

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- o Floor plans showing location of hot water piping, chilled water piping, ductwork (ductwork shall be drawn to scale using the double line method), and location and cfm of supply diffusers and return registers.
- o Location plans and elevations of air conditioning equipment.
- o System flow schematics.
- o Control sequence description.
- o Equipment schedules.
- o Plumbing floor plans and isometrics.
- o Mechanical site plans including potable water piping, fire protection water piping, air distribution piping, sanitary system equipment and piping, sanitary lift stations, cooling tower locations, cooling tower supply and return piping, etc.



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SECTION 01026

DETAILED REQUIREMENTS - MECHANICAL RESEARCH EQUIPMENT

PART 1     SCOPE

- 1.1           This section of the specifications outlines the detailed requirements to be met by the Architect/Engineer (A/E) in the design of mechanical research equipment.

PART 2     DRAWINGS

- 2.1           Because the design of research facilities typically involves many different engineering disciplines, special attention must be given to preparing clear and concise drawings, in particular the top level overview and assembly drawings. These drawings require all necessary notes and drawing cross references to show an overview of the scope of work and to identify the different disciplines involved in the project. A drawing list must be identified on the overview drawings, which can be referenced to find design details of each particular engineering discipline.
- 2.2           In addition, where retrofit work is required, drawings shall show clear and concise definition of the extent of work, materials, or components to be removed or reused, and materials or components to be Government supplied. The critical factor for developing useful retrofit type drawings is complete and accurate site investigation work.
- 2.3           For mechanical research equipment designs, detail drawings are required to completely define the geometry and all critical features such as manufacturing tolerances weld sizes, surface finish requirements etc. The design details shall be clearly and concisely shown rather than providing overview drawings which would rely on the judgment of the manufacturer for interpretation.
- 2.4           For additional details on drawing requirements, see Sections 01022 and 01035.

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PART 3      CALCULATIONS (GENERAL)

- 3.1      In the engineering and design of research facilities, and in particular, the final design of the NTWC, the materials used and systems designed are exposed to extreme operating conditions. Very tight machining tolerances and positioning accuracies are required for most of these projects, as the systems are exposed to very high loads, pressures, and/or flow rates. To insure that the performance specifications can be met and that the systems meet all safety requirements, extensive design analysis must be completed. These calculations include structural analysis, as well as fluid dynamics analysis. Finite element analysis is required for certain critical system components. The design analysis shall be well documented, with all assumptions, variables, and applicable reference document identified.
- 3.2      Preliminary calculations and an outline of additional calculations to be done for the preliminary design are to be submitted along with the preliminary progress prints. Design calculations shall be submitted along with the drawing review package. Calculations shall be bound in an appropriate binder with index attached.
- 3.3      Particular attention must be placed on complying with all applicable code requirements. The applicable codes are identified in Section 01022.

PART 4      SPECIAL PRODUCTIVITY REQUIREMENTS

- 4.1      Special attention shall be given in the PER and preliminary design to the stringent productivity requirements defined in Section 01022. It is anticipated that mechanical equipment specified will have to be extremely reliable, easily maintained, and if malfunctions occur, the failed equipment rapidly detected and replaced. Redundant components or systems may be required if reliabilities are low. The productivity requirements shall be considered in all phases of the design process.

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SECTION 01027

DETAIL REQUIREMENT - PROCESS SYSTEMS

PART 1 SCOPE

PART 2 DETAILED PROJECT REQUIREMENTS

- 2.1 All gaseous process systems shall be designed in accordance with ANSI B31.3, Chemical Plant and Petroleum Refinery Piping. New components for these systems shall be in accordance with the ASME Pressure Vessel Code or the appropriate ANSI standards. Pressure vessels such as filter bodies and storage vessels shall have the ASME stamp.
- 2.2 Hydraulic systems shall be designed in accordance with ANSI B31.3, Chemical Plant and Petroleum Refinery Piping and the applicable section of the ANSI National Fluid Power Association Code. Graphics symbols shall be in accordance with ISO Section 1219, Fluid Power Graphic Symbols.
- 2.3 In addition to the minimum requirements of the above codes and standards, the design of the process systems and components shall conform to the requirements of LHB 1710.40, "Safety Regulations Covering Pressurized Systems" dated July 1984.
- 2.4 All valves of the process systems shall conform to ANSI B16.34, Valves, Flanged and Butt-Welded End. All installed valves shall have flanged, clamped or O-ring union ends for ease of removal from the system.



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SECTION 01028

DETAILED REQUIREMENTS - CONTROLS

PART 1 SCOPE

1.1

PART 2 DESIGN STANDARDS

- 2.1 The design shall conform to the provisions of NASA Facilities Engineering Handbook NHB 7320.1B; Public Law 91-596, Occupational Safety and Health Act; the National Electrical Code; the National Electrical Manufacturers Association; the American National Standards Institute; the National Electrical Safety Code; and applicable UL, CSA, FM, NEMA, or ANSI/IEEE design practices for control systems.

PART 3 DESIGN CALCULATIONS

- 3.1 Design calculations shall be provided to verify design conformance to performance specifications as listed in the applicable paragraphs of the Preliminary Engineering Report. These calculations shall include verification of the following PER specifications:

- A. Section A - Paragraph 2b (x, y, z axis accuracies, speeds)
- B. Section A - Paragraph 4b (x, y, z accuracies, speeds)
- C. Section B - Paragraph 3b (environment, accuracies, speeds)
- D. Section C - Paragraph 1b (temperatures, pressures)
- E. Section C - Paragraph 3b (accuracies, speeds)
- F. Section C - Paragraph 4b (accuracies, speeds)
- G. Section D - Paragraph 1b (accuracies, speeds)
- H. Section D - Paragraph 4b (environment, accuracies, speeds)
- I. Section F - Paragraph 3b (environment, accuracies, speeds)
- J. Section F - Paragraph 4b & C (environment, accuracies, speeds)
- K. Section F - Paragraph 6b (accuracies, speeds)
- L. Section 3 - (HRN PER) - Paragraph B.2. (accuracies, speeds)
- M. Section 3 (HRN PER) - Paragraph C.2. (accuracies, speeds)

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3.2 Load calculations shall be made to determine required current and voltage loads on the AC electrical supply system.

3.3 Deleted.

PART 4 DRAWINGS

The A/E shall prepare separate electrical drawings which shall be clear and concise, with notes, references, construction details, and all information necessary for a complete installation. Separate drawing presentations shall be prepared for each system. Drawings shall conform to DOD-STD-100, "Drawing Requirements Manual."

4.2 The drawing package for each system shall include, as a minimum, the following:

4.2.1 Drawing Classes - The required classes of drawings are defined as follows:

4.2.1.1 COVER SHEET AND LIST OF DRAWINGS

This drawing shall be the top drawing associated with any drawing package. It shall specify the project, facility, general location, a list of all applicable top level drawings contained in the project package, and list for reference top level drawings from other existing systems.

4.2.1.2 SYSTEM/BLOCK DIAGRAM DRAWING

This drawing shall define the system or block nature of the project ... or system. It shall illustrate the functioning and general philosophy of the major system components and their association with each other as well as existing system components. This drawing may not be required for a simple, stand alone project or system where the schematic drawing is self-explanatory.

4.2.1.3 SCHEMATIC DRAWING/LADDER DIAGRAM

This drawing shall show all major components or assembly members of the project or system. It shall show the general connection and interface of all system devices and components without scaling of the location, physical size, and interconnection methods. A legend table shall identify symbols and labeling nomenclature. On a large multi-component project, several drawings may be required including high level system

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schematics/ladder diagrams and component assembly level schematics/ladder diagram.

4.2.1.4 ARRANGEMENT DRAWING

This drawing shall show the physical scaled location (plan, elevation, side, section) for each component or assembly unit shown in the schematic or ladder diagram. This drawing may contain a list of materials and may reference specific assembly unit drawings.

4.2.1.5 INTERCONNECTING DRAWING

This drawing shall show the scaled location and interconnecting interface between all major components and/or assembly units including components or devices presently existing in the facility.

4.2.1.6 ASSEMBLY AND PARTS LIST DRAWING

This drawing shall show the scaled assembly (front, back, side, top sections) of a specific unit or device shown in the arrangement and/or interconnection drawings. This drawing shall show the location of all major internal components. This drawing shall contain a parts list for this specific assembly and list the applicable drawings associated with internal wiring and special mounting details.

4.2.1.7 INTERNAL WIRING AND MOUNTING DETAIL DRAWINGS

This drawing shall show the details of internal wiring and component interconnection. Any special mounting or fabrication specifics shall be shown or detailed in notes where applicable.

4.2.1.8 CABLE ASSEMBLIES/WIRING HARNESSSES/PC LAYOUTS

Any specialized assemblies such as cables and PC boards shall be drawn per the applicable accepted commercial practice for that type of assembly. Special mounting or fabrication specifics shall be shown or detailed in notes where applicable.

4.3 Manual - The A/E shall provide a preliminary Operating Manual for the controls provided including an operating description with emphasis on sequence of operation and operator interactions. Binding is not required.

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Commercial manuals shall be provided for commercial equipment and commercial manuals shall be tied together and indexed in this preliminary operating manual.

**PART 5      SPECIFICATIONS**

**5.1**            The A/E shall prepare complete electrical specifications covering all phases of control system work and all electrical equipment included in the design.

**5.2**            The electrical specifications shall include the following items as a minimum:

**5.2.1**          General requirements, material, workmanship, codes, submittal requirements.

**5.2.2**          Hardware design specifications required for mechanical research equipment including (but not limited to) motors, motor drivers, owner supplies, local control station/box, operator control panel, computer interfaces, hardwired permissives/interlocks/limits.

**5.3**            The control system design guidelines to be used include operations in manual mode, auto (or micro) mode, and computer mode.

Requirements for each mode are as follows:

**5.3.1**          Manual Mode Operation - Unless ruled out for safety reasons, each control system installed shall have a MANUAL mode of operation where operator inputs can directly affect the items under control (i.e., jog buttons for motors). This system shall have the highest reliability in operation since it is the fallback system to be used in case of a malfunction of equipment in one of the other modes. Hardwired analog or relay subassemblies shall be used to maximize reliability. If microprocessor based controllers are used in implementing this mode, they shall be proven, off-the-shelf equipment of the highest reliability, specifically designed (and tested) for the process control industry. They shall be easily replaceable, and shall require minimal user programming such as do the Moore 352 Series of single loop analog controllers. If PLC-based digital controllers are used for manual mode operations, they must be off-the-shelf items of proven reliability, with easily replaceable parts, and shall require minimal programming in a high level language (ladder logic, or equal) such as do the TI series of PLC controllers. I/O devices providing easy state diagnostics (i.e. LED's on relays) shall be used as much as possible.

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- 5.3.2 Auto Mode Operation - Auto mode of operation is when a closed loop feedback system is used to drive the item under control to an operator entered setpoint. This mode depends on the correct functioning of the feedback transducer, the controlling logic, and correct selection of loop gains for the system. Since incorrect gains or significant changes in external conditions can cause oscillations which may cause a hazard condition to occur, this mode is less reliable in operation than manual mode. A microcomputer-based system may be used in this mode to perform necessary calculations to close the loop. That microcomputer, if it does not meet all the criteria listed in Paragraph 5.3.1 for highly reliable, off-the-shelf devices, shall be used only in conjunction with external highly reliable devices which can take over in case of a failure in auto mode.
- 5.3.3 Computer Mode Operation - Computer mode of operation is when setpoints are generated by an external computer rather than being entered by the operator into the micro or controller directly. In this case, a data link must be established with this external computer and pertinent data may be based back and forth between the micro and the external computer. In certain cases (and with adequate safeguards in place) limited re-programming of the micro may be accomplished using the external computer.
- 5.3.4 Manual/Auto/Computer Mode Functions - When microcomputer that is not an off-the-shelf highly reliable device (i.e., one that is designed and configured especially for this application and does not have the long history associated with off-the-shelf items used in the process control industry) is used in a control system, it shall be backed up with hardwired highly reliable analog (or relay or PLC) devices which can take over upon a failure or malfunction in the micro or in feedback devices. Critical permissives/interlocks shall be fed both to the microcomputer and to hardwired highly reliable logic. The hardwired highly reliable logic system shall make the decision that the microcomputer be allowed to control the item under control. The hardwired logic system itself shall be able to provide the operator sufficient control (i.e., jog buttons) to bring the item under control back into the SAFE condition if it becomes necessary to take control away from the microcomputer. Thus manual mode operation will use only hardwired, highly reliable devices, and computer mode operation must be backed up with an auto or manual mode where hardwired, highly reliable devices are used.

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- 5.3.5 I/O Wiring - Guidelines for designing I/O wiring for process control systems can be found in the following publications:

NEMA ICS2-1983, "Standards for Industrial Control Devices,  
Controllers and Assemblies"  
NEMA ICS3-1983, "Industrial Systems"

In addition, wiring carrying analog signals greater than 10 feet long shall use current loops, filter buffering, shielding, guarding, opto-isolation and/or other means of protection against extraneous noise contamination. Cable grounding shall be planned to minimize ground loops. Contacts driving relays (or equivalent devices) in critical or safety related circuits whose wiring lengths exceed 10 feet shall be located on the "hot" side of the relays to minimize the chance of a wiring short to ground causing unwanted relay activation. Wiring external to chassis shall be rated 300 VDC minimum and shall be 22 AWG or larger unless it is a part of a cable or enclosed harness rated 300 VDC or better. All I/O wired and/or cables shall be marked with suitable permanent markings as to source and destination.

- 5.3.6 Operator Interfaces - Devices for use by the system operator (thumbwheel switches, pushbuttons, readouts, touchscreens) shall be positioned so that the most frequently used items are in easily accessible locations. Devices shall be grouped by function. Device groups shall be laid out in accordance with a written plan of operation of the facility. Industry standards such as:

"Human Factors Engineering"  
by Ernest J. McCormick  
McGraw Hill Co. 1982  
or  
MIL-HDBK-759A, "Human Factors Engineering Design for Army  
Equipment"

shall be consulted to maximize ease-of-use of the layout.

Touchscreens (or display terminals) used for operator I/O shall be designed for ease-of-use, and shall display data grouped as to function and importance. Displays shall not look "cluttered." Multiple screens or pop-up "windows" may be used if single screens become too cluttered. Safety related parameters, however, shall appear on all screens in case of an emergency condition. Special "operator acknowledge" procedure shall minimize the chance for operator error during critical data entry.

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- 5.3.7      **Safety Related Devices** - Safety related devices (interlocks/ permissives/limit switches) shall be installed whenever there is a danger that operator error or a single point component failure can cause a hazard to personnel and/or major damage to equipment. For equipment remotely located from the control station this shall include: devices to determine the state (energized/unenergized) of the system, devices to give assurance to maintenance workers that inadvertent turn-on cannot happen while the equipment is being serviced, and devices (fixed or movable) to ensure that the controlled item cannot run into other items due to operator inattention or component failure. These devices shall be highly reliable items and shall be connected to highly reliable logic.
- 5.3.8      **Safety Related Software** - Software used in equipment where program errors (or gain coefficient errors) can cause a hazard to personnel and/or major damage to equipment shall be protected against accidental loss or unauthorized changes. This normally means software shall be in EPROM or EEPROM and require specialized access (internal switches or passwords), or specialized equipment (EPROM or other programmers) to change. Full documentation and accountability shall be maintained on this software.



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SECTION 01030

GUIDE FOR PREPARING NASA PRELIMINARY ENGINEERING REPORTS  
(PER)

1. General. The PER will be the product of a detailed analysis of user requirements which evaluate alternative solutions and determine the basis for design which will result in the lowest possible life cycle cost for the facility work proposed. The PER will incorporate all information necessary to formulate a basis for a design. It will include the basis for the requirements a descriptive analysis which will describe the functions of the facility or facility work, evaluating different approaches and justifying recommended solutions; a detailed cost estimate which will include additional and reasonable escalation and contingency factors; a detailed construction schedule (usually a time-bar Gantt type chart which will take into account program requirements, fund availability, seasonality, etc.); and, as applicable, plot plans, drawings, schematics and equipment lists, real estate requirements, foundation requirements, erosion control, pollution control and other environmental concerns, fire and safety requirements and other similar requirements. Although most Construction of Facilities (CofF) projects will be of a building type nature and many will exceed \$250,000, some projects will be less in scope, and/or be primarily special systems or equipment oriented. For such projects, only those provisions of this attachment which are suited to presenting a project requirement and analysis, and establishing a cost estimate and schedule, are applicable to the PER preparation and content.

2. PER Format. The following format is prescribed:

- a. The PER shall be either 8" x 10 1/2" or 8 1/2" x 11" paper, bound on the left side with removable fasteners.

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- b. Immediately inside the front cover and bound into the PER shall be the Field Installation Director's forwarding letter to NASA Headquarters. This will be followed by the A-E firm's or other developer's letter of transmittal if the PER was not accomplished in-house. A table of contents shall precede the body of the PER.

3. PER Content. The body of the PER will include an appropriately detailed treatment of the numbered sections set forth below:

**SECTION I. REQUIREMENT STATEMENT.** This section will normally be developed by the user, or it will be developed in full coordination with the user. It will set forth the programmatic or institutional need to be met. It will include the basis for the requirement or problem to be overcome and the schedule to be met, including a full explanation of the timeliness (why now?) of the work proposed.

**SECTION II. DESCRIPTIVE ANALYSIS.** This section will consist of a complete and thorough narrative supplemented, if appropriate, by schematics of the functions and operations to be performed in the facility. The section will be prepared through a completely coordinated effort with the user. If the facility concerned is in the administrative category, the types of activities, numbers and kinds of personnel, functional relationships dependence or independence of the various activities will be described. The descriptions for a laboratory facility will set forth the types of activities or research to be performed within the laboratory as a whole, and within individual component laboratory units, including processing activities, equipment requirements, and utility needs. Production and similar types of facilities will include a description of the various operations or functions of each specific area with the flow of people or materials through the various processes.

- A. Layout/Functional Relationship Schematics. This will be a single-line schematic plan(s) or diagram(s) evolving from the facility project or work descriptions. A narrative will accompany the plans which will describe alternative configurations studied and the reasons for rejection. For habitable building type projects, the gross and net square feet of space allocated to individual functions or organizations will be stated. These plans should also reflect the housing capacity, equipment layout and, if appropriate, utilities requirements. A matrix chart form may be utilized for utilities requirements, as appropriate.
- B. Site Development Schemes. For complex projects, a simplified schematic type site plan may be necessary to show all pertinent information, such as existing and proposed facility location, proposed real estate or easement acquisition, site relationship factors, buffer zones, topography and general drainage, vehicular circulation

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system, utilities, etc. Normally this information can be indicated on the site plan drawing (not a schematic) required under Section V.A.(3)(a)

- C. Foundation Design. Included will be an analysis of the proposed foundation scheme, including an evaluation of alternative designs and reasons for rejection.
- D. Structural Design. This will describe the recommended structural system, including the reasons for selection. Other systems considered will also be set forth including the reasons for rejection. A comparative cost analysis for the various structural systems will be provided, if appropriate. A typical schematic framing plan may be shown, if needed for descriptive purposes.
- E. Mechanical Design. This will describe the recommended mechanical system, as well as alternative systems including life cycle cost analyses with energy conservation considered as a prime design factor. Normally, this will include all Heating, Ventilating, and Air Conditioning (HVAC) systems, and plumbing. As the project nature may require, any other mechanical systems may be set forth in this section, or covered under II-H., Special Systems and Equipment.
- F. Electrical Design. This will include an analysis of the recommended power distribution system, including all services and voltages; special power; such as uninterruptible, emergency or back-up power, telephone distribution system, lighting system, connected loads, and a single-line wire diagram will make up this section. A life cycle cost analysis of the recommended as well as alternative systems will be included, as appropriate with energy conservation considered as a prime design factor.
- G. Selection of Primary Materials and Finishes. All proposed materials and finishes to be used in the facility for foundations, frame, walls, floors, roof, etc., will be briefly specified (outline specifications), including an analysis of alternative materials and a life cycle cost analysis, as appropriate.
- H. Design of Special Systems and Equipment. Many NASA facilities will require additional coverage to provide a complete preliminary design. Special systems and equipment will require analysis, including evaluation of alternative systems and a life cycle cost analysis, with energy conservation given appropriate emphasis.

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- I. Design of Fire Protection and Safety Systems. An analysis and design criteria for all proposed fire protection and safety systems will comprise this section, as well as an assessment of the specific hazards which will require the proposed systems.

SECTION III COST ESTIMATES

A. Engineering Estimate (E)

- (1) The cost estimates shall be derived from the drawings prepared in the development of the PER, and on the basis of the construction criteria employed.
- (2) The estimates shall cover all labor and material costs for each item and include building type collateral equipment which would usually be furnished by a contractor and installed as a permanent part of the building; they shall also include overhead, taxes, insurance, social security and similar costs. All other collateral equipment will be listed or reasonably grouped and the costs therefore will be a part of the facilities project or work package. Estimates should be based on current prices applicable to the site, preferably the latest mid-calendar year price experience. The estimates should indicate the basis used.
- (3) It is essential that the field installation submission of this information be in considerable detail (even though subsequent editing at the Headquarters level in preparation for the formal Office of Management and Budget or Congressional submission may result in consolidation or regrouping of certain detailed breakdowns) by each fiscal year for which funds have been provided or will be requested.

There is increasingly more emphasis on the details of construction cost estimates by reviewing elements. For this reason, it is necessary that units of measure, quantities, and unit cost data be shown for each significant item which can reasonably be identified and quantified. The use of "Lump Sum" - "LS" will be avoided as much as possible if meaningful quantities and unit costs can be applied.

- (a) Interest in Real Estate - If the project includes proposed land acquisition, or other interests in real estate, show appropriate breakdown identifying land cost and easement costs.

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- (b) Site Development/Utilities - Enter all costs normally associated with developing the site, such as site clearance and demolition, earthwork and landscaping, storm and sanitary sewage, mechanical and electrical utilities, roads, bridges, marine facilities and airfield pavements. Elements of this work should be identified as separate procurement entities, if such packaging would optimize procurement strategy and project control.
- (c) Building/Structure (Within 5 Foot Line) - The following categories of construction costs are to be included, and packaged in as many procurement entities as reasonable:
  - (i) Architectural/Structural - Enter all costs normally associated with foundations, structural framing, walls, roofing, finishes and specialities.
  - (ii) Mechanical - Enter all costs normally associated with mechanical building equipment such as heating, ventilating and air conditioning (HVAC), and plumbing. Also include built-in non-severable mechanical R&D equipment. If appropriate for optimum procurement purposes, identify such R&D equipment as one or more segments.
  - (iii) Electrical - Enter all costs normally associated with electrical building equipment, such as transformers, motor starters and control centers, lighting fixtures, communications systems, wiring and distribution systems. Also include built-in non-severable electrical R&D equipment. If appropriate for optimum procurement purposes, identify such R&D equipment as one or more segments.
- (d) All Other Collateral Equipment - Enter all costs for collateral equipment which is other than building-type equipment and will be built-in, affixed to, or installed in real property in such a manner that the installation cost will be substantial. Include cost for special foundations or unique utilities service, or for the facility restoration work required after such equipment is removed.
- (e) Special Features - When it is deemed significant to identify separately special items, include in this entry such costs as necessary to provide for Plant and Personnel Protection

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(such as fallout shelters, fire protection, flood control, medical facilities); environmental concerns (air, water, noise, special sewage treatment); and any secondary functions of the project such as those provisions necessary to meet community needs or interfaces with other agencies or organizations. See Section V. C (2), Institutional Environmental Concerns and Impact Statements.

(f) Total - The sum of lines (a) through (e).

- (4) Related Items/Actions. Explain any related items such as procurement, R&D activity or facility projects, which are not covered in the above Engineering Estimate or in "Costs Not in Estimate" (paragraph E below).
- (5) Where cost estimates may be considered unreasonably high or low for the type of facility proposed, an explanation shall be furnished. This requirement shall apply to individual items of an estimate as well as the estimate for the project or work as a whole. Since unit and total costs for like facilities are compared program-wide by reviewing authorities, appreciable deviations must be explained.

### B. Budget Estimates (B)

- (1) A budget estimate obtained by applying appropriate factors to the engineering estimate shall be included. First, an appropriate design and construction contingency factor must be applied. If current economic trends indicate it to be appropriate, a cost-rise factor to the projected mid-point of construction may also be added to the engineering estimate to provide for possible future rise in construction cost between the time the PER is prepared and the time the bids may be received. This factor, if used, shall be clearly indicated, as well as the time period it is intended to cover, and the basis used to determine the magnitude of the factor (e.g., "Engineering News-Record," March 1974). The budget estimate shall be computed by the following formula:

$$B = E (1.00 + C) (1.00 + F) (1.00 + G)$$

B is the budget estimate

E is the engineering estimate

C is the contingency factor

F is the cost-rise factor (when used by the estimator)

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G is the outside agency and/or A-E firm administrative cost factor (when used, this factor shall be explained, and the prospective outside agency identified).

Careful consideration should be given to the various percentages applied when calculating the budget costs. These percentages are variable and should be commensurate with the nature of the work involved and the status of design. The percentages used shall be stated in each case. When agencies outside NASA are engaged for contract administration and inspection services, the percentage charged by such agencies shall be applied to the applicable items in the estimate and the percentage used shall be stated. When contract administration and inspection is to be accomplished in-house but supported or assisted by architectural/engineering firm effort, the estimated cost of this A-E effort becomes a part of the facilities project cost and will be factored into the budget estimate under "G" in the above formula.

- C. Cost Data Format. Cost data identified in Section III shall be reported in the general format under item headings as illustrated on the following page. In the normal manner, the description column and columns 1, 2, 3, and 5 are completed with 5 indicating the product of columns 2 and 3, Column 5 need only be calculated for segment subtotals and larger totals. The "Engineering Estimate" (E) is next translated to a "Budget Estimate" (B) as indicated in the formula shown above. This TOTAL budget estimate is entered in column 6 against line (6) and the relationship of B/E computed. This relationship is then extended to the subtotaled lines of column 5 and appropriate entries made in column 6. Totals should be checked and adjusted rounded off to the nearest \$100. The cost matrix is then completed for column 6 by the quantities in column 2 and entering the quotient in column 4.
- D. Design and Engineering Services. The estimate of the cost to prepare final design, drawings, and specifications and the estimated construction cost shall be shown as separate items. The design costs will not be added to the budget estimate, nor shown in the above Cost Data Format, but indicated under paragraph E, "Costs Not in Estimate."
- E. Costs Not in Estimate. Provide breakout and description of costs listed below which are not included in the project construction estimate but are required to make the facility initially operable.

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- (1) Planning and Design Cost Total (include Design and Engineering Services)
- (2) Other Related Equipment
  - (a) To be purchased
  - (b) Transfer to Excess
  - (c) Existing
- (3) Future Funding
- (4) Activation
- (5) Interest in Real Estate (other than purchase permits and leases only)
- (6) Other (identify)

**SECTION IV. DESIGN AND CONSTRUCTION SCHEDULE.** Indicate graphically, using a "time-bar" Gantt type chart, the estimated number of months required for each of the following: Preparation of final design, plans and specifications, bidding, construction, and facility activation. If more than one construction contract is contemplated, and estimate of the time required for each major contract and the phasing thereof shall be given. "All of these factors will be included in a Project Implementation Plan which may also show the timing, role, and relationship of special A-E services, such as preparation of as-built drawings, construction management activities, long lead procurement items or packages, required extra NASA approvals (such as clearance, from state planning authorities) and the need for resolution of any special problems and constraints to successful completion." Such a plan will be developed by the installation as early as possible in the project planning and design phase to permit the greatest flexibility in implementing the project. If a predetermined "need date" has been given for the facility, such a date should be given.

**SECTION V. APPENDICES TO THE REPORT**

**A. Drawings**

- (1) Each PER shall include a copy of the "General Development Plan" (the normal title for facilities master plan drawing indicating disposition of buildings, roads and installation land area) of the installation on a print reduced to 8" x 10 1/2" or 8 1/2" x 11". The plan shall indicate the location of the project in red. If the General Development Plan is of such scale that the red marking will not accurately indicate the location relative to other associated facilities

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in the vicinity (required for site approval for fire protection, explosive safety distances, etc.), a separate larger scale site map of the immediate area should be provided.

During the preparation of the PER, particular attention shall be paid to requirements or guidelines of local or regional planning agencies, environmental considerations, required safety distances, as well as the consideration of effective land use, topography, accessibility and utility distribution. Outline and indicate on this plan any proposed land requirements, including easements.

- (2) The size of all drawings in the PER shall be 8" x 10 1/2" or 8 1/2" x 11" reduced from a drawing of any convenient size. Foldouts of drawings may be used if the vertical dimension is held to the 10 1/2" or 11" size. Sufficient margin shall be provided along the left side to allow for binding in the PER and margin of about 3/8" shall be provided on the other three sides. All such drawings must be clear and legible, therefore, prints from old tracings that are badly worn are not acceptable. All such drawings must be to scale, with the appropriate scale indicated.
- (3) The number and type of drawings to be included in the PER will depend on the complexity, nature, and magnitude of the facility. For example, the number of floor plans or other drawings on one sheet will likewise depend on the size and scale which will result in a clear presentation. For a project which includes a single-story building with connecting utilities, the drawings will cover at least the following:
  - (a) A dimensioned site plan indicating the total land area involved, general topography, extent of paving and fencing, and utilities.
  - (b) An architectural floor plan (not a single-line sketch), adequately dimensioned and noted.
  - (c) Elevations adequately dimensioned and noted.
- (4) Any additional drawings, sketches, calculations, design data and material used by the A-E to develop the cost estimate shall become the property of the Government; however, this additional material need not be appended to the PER but shall be retained by the installations for back-up support of the estimate.

- B. Real Estate and Easement Acquisition Data. Every project shall be analyzed to determine if NASA has sufficient interest in the real estate. If

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no real estate interest is required, there should always be a specific notation to this effect in Section III. If a project involves real estate or easement acquisition, this must be specifically covered in Sections II and III. This is required for all items where any real estate interests are involved, e.g., minor acquisitions for easements for rights-of-way. For those projects which include requirements for additional real estate or easements, and appendix shall be included in the PER containing the following items:

- (1) A tabulation segregated by type of ownership only, (e.g., private, State or Public Domain), of the acreage proposed for acquisition plus easements for access and utilities, showing assessed value of land, assessed value of improvements and currently appraised value, with the number of owners involved.
- (2) The extent of any street and/or road closings and the extent of any road and/or utility relocations, including a cost estimate for such closing and/or relocation as separate and apart from the land values indicated above.
- (3) The extent and estimated costs of required additional rights, such as mineral rights, timber rights and easement rights, whether outstanding in parties other than the present owners or not, and a statement as to whether title should be taken in fee simple absolute or subject to such rights.

C. Ancillary Investigations

- (1) Erosion Control Studies. The requirements for soils and hydrologic surveys are described in NASA's Facilities Engineering Handbook (NHB 7320.1).

The purpose of these surveys is to determine the soil, water and geologic conditions which may affect (1) runoff and seepage of waters; (2) erosion, sloughing and sliding of soils; and (3) soil and water adjustments required to establish and maintain vegetative covers for the land. Such surveys must be made in new areas being developed where sufficient information is not available to firmly establish the character of the soils, and to form a basis for the control measures to be prescribed. Records of these surveys shall be retained on file at the installation. A summary of such ancillary investigations should be attached when the actual studies and other investigative reports are not included.

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(2) Institutional Environmental Concerns and Impact Statements

From the time the conceptual study is initiated and the facility requirement is established, the assessment of environmental concerns shall be considered as part of the preliminary design effort, and will be documented in the Preliminary Engineering Report. This documentation will demonstrate an environmentally acceptable method of meeting the technical requirement for the facility. In addition, this documentation will become the basis for the preparation of an amendment to an existing or of a new environmental impact statement for final facility design - if such action is required. The decision as to whether an impact statement is needed, and the form it should take, will be made at the time execution of final design is approved.

The requirements for air and water pollution control, noise control, industrial waste control, and other similar environmental concerns are described in NASA's Facilities Engineering Handbook (NHB 7320.1), P. L. 91-190, National Environmental Policy Act of 1969, and the Council on Environmental Quality Guidelines, April 23, 1971. The Federal Regulations on water and air pollution as applied to NASA's facilities are specifically covered in the two NASA issuances, current NMI 8800.3 and 8800.4, respectively. The health and safety requirements are in the Occupational Safety and Health Act.

The requirements for protective construction are described in the current NMI 1043.1, Fallout Shelter Criteria. The requirements for flood control measures are described in current NMI 8800.2.....

In addition the PER shall indicate that coordination required by the Intergovernmental Cooperation Act of 1968, as implemented by OMB Circular A-95 (revised), has been effected, or if not, the basis of exception.

- (3) Other Investigations or Studies. Where the proposed facility project requires investigations or studies in addition to those listed, a summary should be attached as indicated above. These might include a comparative cost analysis for supporting decisions to lease or purchase (construct) general purpose real property, as required under current OMB Circular No. A-104; or a cost-benefit analysis to evaluate the cost and/or benefits of programs or projects when they are distributed over time, as required under current OMB Circular No. A-94.



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SECTION 01031

INSTRUCTIONS FOR ARCHITECT-ENGINEER CONTRACTORS  
IN THE PREPARATION OF  
DRAWINGS AND SPECIFICATIONS

AD.1      Relation of Drawings and Specifications:

AD.1.1      Drawings and specifications shall supplement each other and shall not conflict. In general, drawings should show:

- a. Architectural and engineering design.
- b. Elevations, sections, details and plan views.
- c. Designation of each portion, to allow reference to it.
- d. First sheet of drawings shall be title sheet. On the title sheet, show the following:
  1. Symbols used for wood, concrete, steel, or other materials.
  2. Location of the facility.
  3. Titles of all drawings.
- e. Limits of work.

Specifications shall give all necessary information governing:

1. Materials and workmanship.
2. Inspection and tests.
3. Supplementary contractual requirements.

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4. Necessary information not supplied by the drawings.

- AD.1.2 Terminology used in specifications and drawings shall be the same. If the terminology used in the drawings should vary and revision of the drawings is not practicable, the specifications must reconcile such differences in a manner similar to the following: "Hollow tile (also indicated as 'clay tile' and as 'terra cotta tile')".

AD.2 Selection of Materials:

- AD.2.1 Materials shall be used in a manner that will afford the maximum service at the lowest comparable cost. Maintenance costs shall be weighed against initial costs to achieve maximum economy. Before deciding upon a specific material for design or purposes, the following points shall be considered:

- a. Contemplated life of the construction.
- b. Climatic and operational conditions.
- c. Whether material will be used to the best advantage.
- d. Whether material is a stock item or whether it requires special processing.
- e. Availability of material in the area of usage.
- f. Does the material provide good service under the contemplated conditions of use?
- g. Whether material is proprietary (See Paragraph AD.3.).
- h. Is the material competitive?
- i. Is the material or some of its ingredients scarce or critical?
- j. Life Cycle Costs.

AD.3 Proprietary and Restrictive Requirements

- AD.3.1 Proprietary and restrictive requirements shall not be used when specifying equipment and materials on drawings and in specifications. When brand name or "or equal" is used on the drawings and specifications, unlimited competition consistent with the type of work shall be permitted. Drawings and specifications

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shall be prepared to utilize standard products and current models of equipment meeting the functional requirements of the facility. Proprietary requirements as well as proprietary names shall be avoided.

AD.4 Safety and Fire Protection Features:

AD.4.1 Appropriate consideration shall be given to safety and fire protection in preparing the drawings and specifications. Desirable safety and fire protection features shall be incorporated initially into the project to eliminate costly additions later. NASA fire protection safety personnel are available for consultation and should be consulted.

AD.5 Avoidance of Common Errors:

AD.5.1 There are many phrases and statements placed on drawings which are considered satisfactory in professional architectural and engineering practice, but not acceptable in the preparation of drawings for the NASA, Langley Research Center. The following is a of such items found repeatedly in drawings submitted by Architect-Engineers. After each error or group of related errors, the correct designation is stated.

- |     |                 |   |
|-----|-----------------|---|
| (1) | ERROR           | "As instructed by the Architect"        |
|     | <u>CORRECT:</u> | "As directed"                           |
| (2) | ERROR:          | "As approved by the Architect"          |
|     | <u>CORRECT:</u> | "As approved"                           |
| (3) | ERROR:          | "By others"                             |
|     | <u>CORRECT:</u> | "By the Government"                     |
| (4) | ERROR:          | "See Sheet No. 17"                      |
|     |                 | "See Architect's Drawing No. A-17"      |
|     | <u>CORRECT:</u> | "See NASA Drawing No. LD-000,000"       |
|     |                 | (Always refer to NASA drawing numbers.) |
| (5) | ERROR:          | "By electrical contractor"              |
|     |                 | "By plumbing contractor"                |
|     |                 | "By the plumber"                        |
|     |                 | "By elevator contractor"                |

EXPLANATION: Usually no statement is necessary. The Government recognizes only the prime

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Contractor; the breakdown into trades is not in accordance with Government practice.

In the event work is shown on the drawings which is not included in the scope of the contract, use the following:

CORRECT: "Not included in this specification"  
"By Government"

(6) ERROR: "Transite"  
CORRECT: "Cement asbestos"  
(Proprietary names are not permitted)

### AD.6 General:

AD.6.1 The technical specifications for a construction project form a part of the construction contract. Project specifications should as brief as possible, definite, and free of ambiguities and omissions which might cause controversies and Contractors' claims for additional compensation.

### AD.7 Scope and Description:

AD.7.1 This should give the bidder the principal phases of the work. When buildings are involved, describe and give overall sizes and heights, and type of construction. Do not merely state that the work includes masonry, carpentry, concrete work, and so on. The general description is used in the "Invitation for Bids" and it is important that all phases of the work be included.

### AD.8 Drawings Accompanying the Specification:

AD.8.1 All drawings that form a part of the contract shall be listed in the specification and shall be identified by the title and NASA Drawing Number. When revised drawings are listed, show revision date and letter.

AD.8.2 The drawings furnished by the A-E shall permit ready reproduction by conventional printing methods. In addition, the quality of drafting on mylar shall be such as to permit clear and legible reproductions of the original by microfilming (and subsequently enlargement) as well as by commercial, high speed, offset printing methods. The A-E shall use materials and methods consistent with this requirement.

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AD.9 Standard Specifications:

AD.9.1 Under this heading, all Government and non-Government specifications and standards that are referenced in the project specification or on the project drawings, shall be listed. List correct number, symbol, date, full title, and, if amended, the most recent amendment after the title thus, "including amendment XXX". The date listed should be the date of the specification and not the date of the amendment or addendum. Care shall be exercised in the use of trade association standards to ascertain that they are not restrictive.

a. Specifications. In referencing Federal, Military and Standard specifications or codes, the following rules should be followed:

(1) Do not copy portions of standard specifications in the project specifications.

(2) Avoid reference to specific paragraphs in the standard specifications, since it limits the requirements of the standard to the paragraphs referenced.

(3) Avoid repeated references to a standard specification within the same section.

(4) Read carefully all notes on the use of the standard.

(5) Specify types, classes, weights, and similar requirements as applicable.

AD.10 Phraseology:

AD.10.1 The following instructions related to common errors in phrasing have evolved from experience with A-E specifications:

(1) Under "General Requirements" do not say "the work consists of". Drawings should show scope; if necessary to list certain parts say, "the work includes".

(2) In lieu of reference to accompanying drawings and/or the Contracting Officer, use the words "as shown", "as indicated", "as detailed", or "as approved", "as directed"; but not "as on the drawings" or "as approved by the Contracting Officer".

- (3) Do not use the phrase "in accordance with the Contracting Officer's Order". The Contracting Officer must specify that all work must be in accordance with the Contracting Officer's Order.
- (4) There are two types of work: (a) the Government as the Employer and, (b) the Contractor. Such expressions as "subject to the approval of the Architect", "when in the opinion of the Architect", "mason", or "subcontractor" are not to be used.
- (5) Do not use the word "or" for indefinite for bidding and construction purposes.
- (6) Do not use the word "include, unless" to include all materials and reinforcement of the work. The specification should be clear, but little, for the specification sentence and the sentence should be "unless stated otherwise". In fact, there is no project, to which the specification should be clear, to which the concrete work floor or store should be clear, to which the paragraph of the drawing should be clear, to which the several classes of their scope should be clear, to which the to mention should be included.
- (7) Minimize the use of the paragraph and particular paragraph under which the following type of work is covered. References and in no case use the word "or". If necessary to refer to a particular title and the section title of the drawing, the Cross references of the drawing are necessary; "Painting of the woodwork" or "Painting is specified."

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- (3) Do not use the expression "to the satisfaction of the Contracting Officer", or "satisfactory to the Contracting Officer". The contract states specifically that all work must meet the approval of the Contracting Officer.
- (4) There are two parties to the contract: (a) the Government as represented by the Contracting Officer and, (b) the Contractor. Therefore, do not use such expressions as "subject to the approval of the Architect", "when in the opinion of the Architect", "this Contractor", "mason ", or "subcontractor".
- (5) Do not use "etc."; the term is too indefinite for bidding and purposes.
- (6) Do not use expressions such as "The work required shall include, unless stated specifically otherwise, the provisions of all materials for and the installation of all concrete, including reinforcement, necessary to the construction and completion of the work in accordance with the drawings, the specifications, and the intent thereof." This sentence means but little, for unless the intent of the drawings and specifications is indicated more adequately elsewhere, the sentence adds nothing, particularly in view of its phrase, "unless stated specifically otherwise", when, as a matter of fact, there is often no exception to be made. For a particular project, to which such might be applicable, this statement should be changed to read, "General requirements - The concrete work includes column footings, wall footings, first floor or storeroom and pipe trenches." In most cases, this paragraph can be omitted advantageously as an examination of the drawings indicates clearly the exact limitations of the several classes of work and a definition in the specifications of their scope is superfluous and may be contradictory by failure to mention something shown clearly and intended to be included.
- (7) Minimize the use of cross references and in no case use paragraph numbers for this purpose. If necessary to refer to a particular paragraph, do so by its title and the section title under which it is to be found. Cross references of the following type are totally unnecessary; "Painting of the wood work is covered under "painting" or "Painting is specified."



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- (8) Do not place upon the bidder the responsibility for the possible inaccuracy in, or the lack of, information on the part of the Government; e.g., never use sentences similar to "Although the drawings indicate approximately the conditions that are likely to be found, intending bidders should satisfy themselves as to the actual conditions, for while they are believed to be shown, the Government does not guarantee the accuracy of the information given, and bidders shall assume all responsibility in the use of such." Remember that the Government is responsible for the accuracy and sufficiency of the information it gives to bidders or contractors and the A-E is in turn responsible to the Government for the same information. Checking of drawing dimensions, tolerances, etc., against physical conditions in performance of the contract should be required where appropriate.
- (9) Do not include "warranties, data, and information, etc." under section or paragraph covering equipment. Include data and information required under Section 1.
- (10) Do not set up a paragraph in the various technical sections entitled "work not included". Specify the work that is included under the respective sections.

Any equipment or services which are not to be included shall be listed separately under Section 01000 of the Construction Contract Specifications.

(11) Misuse of Words:

- (a) Do not confound any and all; e.g., "Any defects shall be made good, etc." should read "All defects shall be made good, etc."
- (b) Do not confound either and both; e.g., "Sheet metal shall be painted on either side," should read "Sheet metal shall be painted on both sides." "Either" implies a choice.
- (c) Do not confound or and and; e.g., "It shall be free from defects of workmanship and material which would impair its strength or durability." Interchanging the two words in this sentence results in an entirely different meaning.

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- (d) Words having varied or indefinite meanings should be avoided.

Examples:

1. The equipment shall be removed from the building during the alterations thereof and shall be installed after completion of the alterations.

Do not say: "The equipment shall be removed and replaced as indicated".

2. The existing culverts shall be removed and shall be installed in the new locations.

Do not say: "The existing culverts shall be replaced as indicated on the drawings."

3. The electrical wiring shall be renewed.

Do not say: "The electrical wiring shall be replaced". This implies reinstallation of the old wiring.

- (12) Avoid ungrammatical omission of the articles; e.g., "Contractor shall paint ceiling of office" should read "The ceiling of the office shall be painted."

- (13) Use of Abbreviations and Symbols: In general the use of abbreviations should be avoided, except in the case of those which are generally understood and accepted, and can be used economically; e.g. psi, cfm, kw. (the use of ft., in., lbs., %, do not offer great savings). The use of symbols is undesirable for three basic reasons: (1) Most are difficult to produce on a typewriter and stencil; (2) They frequently have more than one meaning; (3) The typist may not know what is intended and thus cannot produce the proper symbol. Feet ('), inch ("), degree ( ), pound and number (#) should be written out, except that number may be abbreviated (No.). In the text it is preferable to spell figures, except where they give dimensions, for example, "ten buildings", "100 feet long"; however, "one" and "zero", where used singly shall be spelled out. Never use both the written and numeral figure "ten (10)".

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- (14) To standardize phrasing in project specifications, materials should "conform to" a specification and workmanship should be "in accordance with" a specification.

AD.11 Facilities Engineering Handbook:

AD.11.1 In the design of all structures, it is NASA's policy to provide functional facilities of a durability consistent with their mission and the duration thereof. The Contractor shall utilize, to the fullest extent practicable, the NASA Facilities Engineering Handbook, NHB 7320.1B, as appropriate. Upon request, one copy of this handbook will be provided for the use of the Architect-Engineer. Upon completion of design, the handbook should be returned to Langley Research Center, Mail Stop 447, Hampton, Virginia 23665.

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# **National Wind Tunnel Complex**

**Joint Industry Government Team**

**Final Report - March 1994**

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  - (c) JIGT Concept D - Option 5 with Consortium Procurement
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8. Presentation, "*Report of Joint Industry Government Team to the Administrator*"
9. Report from JIGT Support Contractors - Sverdrup Technology, Inc. and ASE-Fluidyne

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# **National Wind Tunnel Complex Joint Industry Government Team Final Report - March 1994**

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## **1. Joint Industry Government Team**

A need for new high Reynolds Number and high productivity wind tunnel test facilities was identified by the aerospace industry. This need was reviewed and affirmed by the Aero-Facilities Task Group, a sub-group under the National Facilities Study. The Aero-Facilities Task Group identified a set of specific performance requirements to be incorporated into these new wind tunnel test facilities. After numerous meetings and reviews, a National Consensus Requirements list was developed for the new National Wind Tunnel Complex. A team of engineers consisting of representatives from NASA (Langley and Ames) and DoD (Arnold Engineering Development Center - Air Force and Calspan, and Army Corps of Engineers) developed the supporting technical, cost, schedule and programmatic information to provide test facilities capable of meeting the National Consensus Requirements. This activity was documented in the "Facilities Study Office Final Report" dated December 1993.

The resulting "high" cost (\$3.22 Billion) and "long" schedule (9.5 years) caused concern about the program viability. Identification of means to reduce the overall program cost and schedule while meeting the National Consensus Requirements were requested by the National Wind Tunnel Complex (NWTC) Program Office. A team that represented industry and Government was assembled at NASA - LaRC to identify the alternative procurement and program implementation methods. The goal was to assess how these alternative methods could impact the overall program cost and schedule. This report is a description of the activities and findings of the Joint Industry Government Team's (JIGT) assessment of the alternative procurement and program implementation methods.

### **1.1 Joint Industry Government Team Charter**

The team was formed to investigate potential cost and schedule savings associated with applying commercial practices for procurement and management to the acquisition of the NWTC. The team was composed of both industry and government personnel. The charter of the team was:

*Convene a Joint Industry Government Team (JIGT) at Langley Research Center, Hampton, Virginia on February 14, 1994, and report the results to the NWTC Program Manager on February 28, 1994*

- (a) *Develop a program plan for the National Wind Tunnel Complex (NWTC) which utilizes "Best Business Practices;"*
- (b) *Generate a cost estimate for Concept D - Option 5 which utilizes a "Best Business Practices" approach for Project accomplishment. An assessment of cost uncertainties should be included;*
- (c) *Produce a master schedule which reflects time lines for "Best Business Practices" and "fast track" scheduling;*
- (d) *Examine other design and construction approaches which may render savings in cost and schedule;*
- (e) *Identify urgent design studies.*

## 1.2 Participants

The JIGT included participants from the following organizations:

NASA Ames	Aero-Systems Engineering, Inc.
NASA Headquarters	AEDC - DoD and Calspan
NASA Langley	Boeing
NASA Lewis	McDonnell Douglas
General Electric	Sverdrup Technology

The specific personnel involved were:

### NASA Langley Research Center

Sammie D. Joplin, Head  
 Earl R. Booth  
 Dennis E. Fuller  
 Blair B. Gloss  
 Drew Hagemann  
 Carl E. Horne  
 Kenneth L. Jacobs  
 Dr. Seun Kahng  
 Charles Laney  
 Henry Livas  
 Thomas Quenville  
 Trish Romanowski  
 John Taylor  
 Robert Wallis  
 George Ware  
 Henry Wright  
 Norma Davis, Secretary

### NASA - Ames Research Center

Nancy Bingham  
 Dan Bufton  
 Dave Englebert

### Boeing

William Dodge  
 Robert Doerzbacher  
 Art Fanning  
 Kevin Watson

### General Electric

Bobby R. Delaney  
 Don Dusa

### McDonnell Douglas

Dave Lalor  
 Dale Siegele

### Sverdrup Technology, Inc.

Jim Gunn  
 Ron Hamilton  
 Ward Johnson  
 Ed Rimpley  
 Jim Thorington  
 Jim Young

Kenneth Mort  
Dr. Frank Steinle

AEDC/Calspan  
Travis W. Binion  
Frank M. Jackson  
Lowell C. Keel  
Philip B. Stich

Aero-Systems Engr. (ASE)  
Dean Long  
Tom Moll  
Leon Ring  
Leon Zacho

DoD/AEDC  
Jim Parker

### **1.3 Organization of the JIGT**

The JIGT was organized into six teams: (1) technical and cost, (2) procurement practices, (3) cost adders, (4) project management, (5) project schedule, and (6) studies. Personnel were typically assigned to provide support to more than one team. A team leader for each team was identified. The team leader was then responsible for ensuring the team understood their role and responsibility, the required products, and delivering the required products on time.

Technical and Cost Team - The technical and cost team was responsible for the assessments of the technical area of the NWTC (WBS 1000-7000). Two basic tasks were identified.

The first task was to review the scope and cost of the WBS elements in Facilities Study Office (FSO) concept A and the Boeing Wind Tunnel Project (1991). Note that the FSO Concept A was intended to be the FSO 's interpretation of the Boeing Wind Tunnel Project. The goal was a mutual understanding of technical approaches and costing techniques. Cost adjustments were made when obvious oversights or omissions were found. Cost differences associated with different technical approaches and risk perception were not resolved. The required products were a revised cost estimate for the FSO Concept A and the Boeing Wind Tunnel Project and a comparison of the differences in technical approach and costs for each WBS element at the lowest possible level.

The second task was to perform an in-depth review of the Concept D - Option 5 technical approach with a focus on how the concept was extrapolated from Concept A. The technical approach and cost estimates were reviewed at the lowest possible WBS level. Any discoveries made during the Concept A review were incorporated into the Concept D - Option 5 cost estimate. Consensus was attempted in all cases for the Concept D - Option 5 costing exercise. The required products were a revised cost estimate for Concept D - Option 5 and a listing of the changes in technical approach and costs for each WBS element at the lowest possible level.

Program Management Team - The Program Management Team was responsible for the assessments of the procurement practices, cost adders, and the Project Management Model(s). Management groups reviewed the Boeing-proposed

Consortium Model, developed an alternative Consortium Model, examined issues associated with formation of an Industry Joint Venture, acquisition approach for the NWTC, and operation of the NWTC. Best business practices were identified by the management group and combined with the Consortium Model to render an overall Project Management Model. Costs for Concept D - Option 5 in areas of project management and cost adders were modified to reflect the new Project Management Model. The required products from the Program Management Team were a Project Management Model, identification of the "Best Business Practices" that would be implemented, and a listing of the cost adders and cost philosophy to be employed.

Project Schedule Team - The project schedule team initially developed high level logic elements and relationships. A sub-group composed of personnel from the Technical and Cost Team generated the detailed logic elements (258 tasks) with associated relationships and assigned tentative durations. The entire JIGT reviewed the resulting network and adjusted it until consensus was reached. The required products from the Project Schedule Team were an integrated program schedule, identification of the project's critical path, and the identification of the midpoint of construction.

Studies Team - The Studies Team was tasked to review the previously generated studies and identify the critical or urgent studies that provided the fundamental configuration parameters and allowed early component baseline decisions to be made. The team also addressed optimizing issues to ascertain if those items were merely cost issues where the required performance could be technically achieved, or if the optimization was required to ensure the required performance could even be met. The required product from the Studies Team was a listing of the urgent or critical studies concentrating on technical issues relative to performance and the associated cost and schedule.

#### **1.4 Tasks for the JIGT**

The general requirements for the JIGT were identified in the team's charter. The detailed tasks or information required to meet the team's charter are:

- (a) Identify Industrial/Commercial Best Practices for procurement of large, (\$2B to \$3B), complex ground-based facilities.
- (b) Identify and document the scope for each level of the WBS to meet the National Consensus Requirements for the NWTC.
- (c) Achieve consensus among the JIGT on the technical scope of each WBS element.
- (d) Develop a cost estimate to accomplish the agreed to scope in each WBS element and document the calculations and assumptions.
- (e) Develop a schedule to implement the NWTC program based on the agreed to scope of each WBS element and document the assumptions.

- (f) Estimate "Risk" as cost growth from the inability to estimate cost accurately.
- (g) Achieve consensus among the JIGT on cost, risk, and schedule at each WBS level.
- (h) Estimate the cost adders with an assumption of an Industrial Consortium implementing the studies, design, construction, and checkout of the NWTC.

## 2. Program Management - National Consensus Requirements

This section provides a discussion on the activities, decisions, and products of the Program Management Team and how they influenced the final cost and management models. Elements provided herein include: (1) a description of the baseline Consortium Model, (2) issues associated with the Consortium (including formation of the consortium, contracts between the Government and the Industry Joint Venture, roles and responsibilities, membership in the Industry Joint Venture, and implementation of the NWTC project), (3) identification of the "Best Business Practices" that were adopted, (4) program staffing, (5) revisions to the Program Management WBS element (WBS 8000), and (6) the cost adders to be employed.

### 2.1 Consortium Model Description

The Consortium Model (See Figure 2.1) was derived from The Boeing Company's Consortium Model previously presented to potential industry participants and to the Government. The Consortium is defined as a teaming of all of the parties; the Government (NASA, DoD, and other agencies), the Government/Industry Management Board, the Industry Joint Venture, and all of the associated contracts. It is assumed with the Consortium Model that the Government would contract with an Industry Joint Venture for the construction and operation of the NWTC. The Industry Joint Venture would be composed of interested industry parties. The Government would administer the contract with oversight provided by a Government/Industry Management Board (staffed at the NASA Administrator level). The Industry Joint Venture would be a "not for profit" entity which uses "best business practices" by member purchasing agents. The Government would own the NWTC after activation, and the Industry Joint Venture allocates use rights and defines membership transfer requirements.

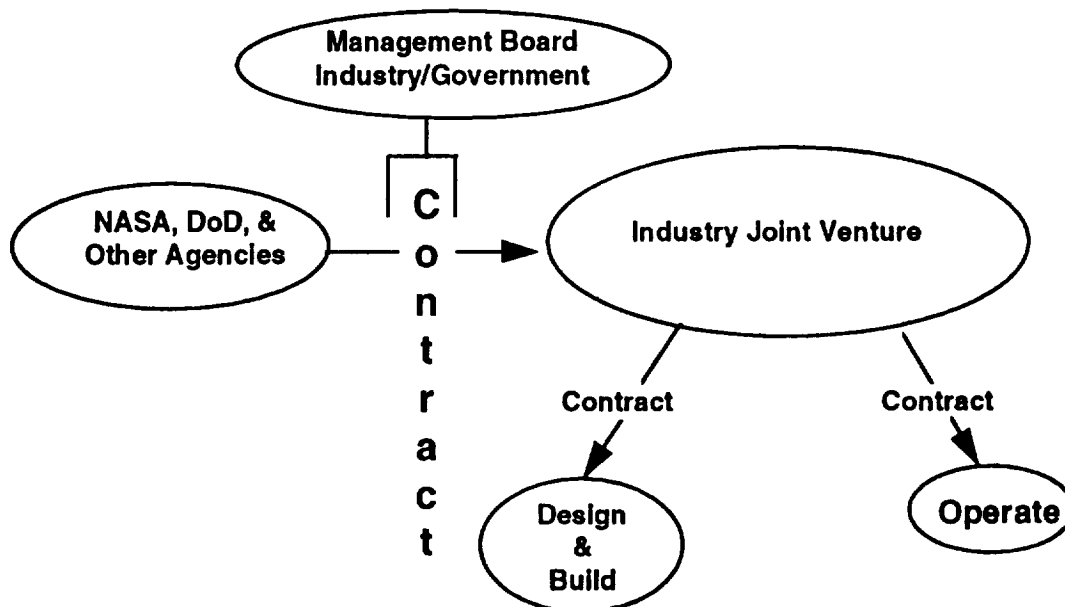


Figure 2.1: Consortium Model

Differences between the Consortium Model and the Boeing Consortium Model are principally concerned with funding. The Boeing Model proposed that the Government pay all costs, including all Industry Joint Venture member staffing costs. The JIGT Consortium model assumes that costs and risk of overrun are shared between Government and the Industry Joint Venture (specific share ratios to be negotiated). The Boeing Model assumes that the Industry Joint Venture will carry the project from study initiation to completion of the facility activation phase. The Consortium Model assumes that the Government will accomplish critical up-front tasks immediately in order to reduce risk (cost uncertainty) and avoid delay, with the formal Industry Joint Venture participation occurring as soon as the Industry Joint Venture can be formed and the proper contracts developed and negotiated.

The Consortium Model assumes that consortium development is conducted in parallel with accomplishment of the critical up-front tasks. It assumes approximately 3 months (from April 1 to July 1, 1994) for development of the Industry Joint Venture and for final contract agreements between Joint Venture members. During this 3-month period, the Government is preparing and receiving authority for a sole source procurement to the Industry Joint Venture for the start of design and analysis. After these actions are complete, the Government issues a sole source contract to the newly formed Industry Joint Venture to start procurements.

The model further assumes that the Industry Joint Venture immediately prepares documentation for, and initiates acquisition of, the first set of design or design-build contracts. The solicitations would be issued "subject to availability of funds." While this is being done, the Government and the Industry Joint Venture are conducting final negotiations for the Consortium Agreement. A signed Consortium Agreement is needed prior to award of any contracts by the Industry Joint Venture to third party sub-contractors. After all parties sign the Consortium Agreement, the Industry Joint Venture proceeds with implementation. The Government's obligation during this initial phase (including termination liability) would be limited to the amount authorized and appropriated.

Specific features of the Consortium Model are:

1. The cost estimate is a total program budget for the NWTC. The cost estimate for the NWTC assumes a green field site with no existing infrastructure.
2. The NWTC constraints, interfaces, and requirements will be clearly defined and will not be subject to unilateral modification by the Industry Joint Venture or the Government during project execution.
3. The technical performance will be consistent with the National Consensus Requirements and the Industry Joint Venture will guarantee that NWTC performance meets requirements at initial operation and for a warrantee period of 2 years.

4. Capital budget will be fixed in both a yearly expenditure profile and total cost. The Industry Joint Venture receives money from the Government based upon predetermined events.
5. Operational readiness date (i. e., ready date for first customer) will be established prior to formation of the Consortium (Industry Joint Venture/Government agreement).
6. No incremental increases in project capital budget will occur during execution of the NWTC Project.
7. Government agencies serve as the benefactor to the Industry Joint Venture in acquiring the NWTC and provide the Management Board with an independent assessment.
8. The Industry Joint Venture will:
  - organize as a legal "not for profit" business entity.
  - utilize industry based methods for procurement and design/build techniques for construction (including concurrent engineering where applicable).
  - assume responsibility for settlement of contract related disputes, protests, and lawsuits.
  - report to an oversight board of Government and Industry at the NASA Administrator level.
9. The Industry Joint Venture contracts with a Prime Contractor (likely a team of specialists) to design and build the NWTC.
  - Contracting is accomplished by "Best Business Practices."
  - Systems Engineering is shared (team approach) between the Industry Joint Venture and Prime Contractor.
10. The Prime Contractor:
  - Is responsible for deciding the degree of concurrency between the design and build activities.
  - Is responsible for contracting with support contractors.
11. Co-locate the Industry Joint Venture and the Prime Contractor's management/systems engineering personnel.

## **2.2 Consortium and Programmatic Issues**

There are numerous issues associated with the formation of the Consortium and the legal connections between the Industry Joint Venture and the Government. These issues are provided as a list of questions to prompt further thought and discussion. Specific recommended approaches are not included.

### **Site Selection**

Site selection impacts the ability of Joint Venture members to accept risk. The Boeing Consortium Model puts the risk on the Government for site selection related cost impacts. Site selection could be done either by the Government, the Consortium, or the Industry Joint Venture and this process needs to be determined. This is an issue for the NWTC Program Office to address.

### Schedule

1. The overall 8 year project schedule assumes no schedule risk mitigation (slack). The formation of the Consortium and contracting between the Government and the Industry Joint Venture must be done in such a way that there is an absolute minimum schedule impact to the project.
2. How long will it take to create the Industry Joint Venture?
3. What duration is required for producing contract documents and for the selection and award of the Industry Joint Venture contract(s)?
4. What duration is required for producing contract documents and for the selection and award of the contracts between the Industry Joint Venture and its contractors?
5. How much schedule time is required to make contract changes and resolve disputes?
6. What is industry's experience in implementing "fast track" construction?
6. Clear authority to proceed and funding consistent with the scheduled expenditures are prerequisites for meeting this 8 year schedule.

### Contractual (With the Government)

1. What special legislation is required to proceed?
2. What is the relationship between the Consortium, the Executive Branch, and/or Congress?
3. What is the relationship of NASA, DoD, and Other Government Agencies and the Industry Joint Venture within the Consortium?
4. What is the reporting plan within the Consortium and between the Consortium and the Executive Branch/Congress?
5. Is the Government protected from dispute liability?
6. What are the audit and expenditure reporting requirements?
7. How are changes (cost, schedule, and performance) identified, validated, and approved.
8. Who approves the performance validation test results?
9. What is the Government's termination liability?
10. When will initial funding be required? How much? What funding profile is required to support the schedule? What contracts will be awarded? How certain is capital funding profiles from year to year?

### Roles and Responsibilities

1. What is the role and responsibility of NASA, DoD, and Other Government Agencies to the Industry Joint Venture and Consortium?
2. Do the roles and responsibilities of NASA, DoD, and Other Government Agencies change throughout the implementation of the program?

3. Who comprises the Oversight Management Board? What is the role of the Management Board and what is its relationship to both the Government and the Industry Joint Venture?
4. What does oversight mean (What is the Management Board's authority)?
5. What types and level of design reviews and design approval are required?
6. How does industry ensure contractor compliance?
7. What level of inspection is required by industry?
8. What level of verification does industry require of contractor inspection?
9. What project status reviews are required? What project controls are utilized?
10. What are the figures of merit for design decisions (see Figure 5.1)?
11. Who has the authority to compromise requirements to optimize cost/schedule/performance effectiveness?
12. Will the Government accept ownership of facilities built and inspected to industry standards?

### Consortium Formation

1. What is the process for becoming a member of the Industry Joint Venture and how is the leader selected?
2. How is the Management Board membership selected?
3. What is the personnel plan (includes staffing level, personnel selection, salaries, awards, etc.)?
4. What is the business plan process for the Industry Joint Venture?
5. What is the legal arrangement between members of the Consortium (Management Board, Government Agencies, and Industry Joint Venture) and when will this legal agreement be in place?
6. What is cost sharing among the Consortium members?
7. How is "contract" performance and staffing shared between the Industry Joint Venture members?
8. What is the liability of the Industry Joint Venture members if one or more decide to leave prior to completion of the NWTC Project?
9. Will the Industry Joint Venture assume the cost of staffing this organization (salaries and travel)?
10. How/who has the liability/responsibility to guarantee performance?
11. How does a participant leave the Consortium?
12. How long will it take to staff the Industry Joint Venture and become operational?

### Funding

1. Development capital from the Government - Is this a one-time upper limit with Industry Joint Venture members funding all cost overruns?
2. Are funds released to the Industry Joint Venture at the beginning of the project, or must the Industry Joint Venture provide working capital?
3. If working capital is required, what is a realistic amount and how is it shared between participants?

4. Who (Government or Industry) covers overruns?
5. Who banks the risk capital and approves its application?
6. What are the incentive mechanisms to reduce cost and increase performance?
7. What is the Capital Cost Recovery requirement and plan?
8. What is the mechanism to assure a multiple year cash flow?

#### Staffing

1. What level, skills, and experience of NASA/DoD/Other Agencies staffing is required?
2. Where will the Industry Joint Venture team be located?
3. Where will the NASA/DoD/Other Agencies team be located?

#### NWTC Operation

1. Where does money received as payment toward capital recovery go?
2. What is the access policy and cost of testing for:
  - Consortium members? (Does capital recovery plan have an effect?)
  - Industry
  - Government
  - Non Consortium Members?
    - U.S. Industries
    - Foreign Industries/Governments
3. How/who resolves conflicts in schedule for operations?
4. How are the Operations and Maintenance activities and future upgrades funded?
  - Will there be a line item in the NASA and/or DoD budget?
  - Will there be a line item in the Industry budget?
5. Do the Consortium participants guarantee a minimum level of testing?
6. When foreign companies pay capital recovery (use charge), where does the money go?

### **2.3 Description of the "Best Business Practices" Adopted**

Best Business Practices is a nebulous term that has different meanings to different organizations. In principle, it means (a) delaying decisions until the fundamental information required for informed decision making is available, (b) solidifying requirements early, (c) constantly challenging approaches until the most cost effective solution has been decided upon, and (d) allowing the organization best suited to perform selected elements of work to perform that work. The best business practices adopted by the JIGT were based upon numerous meetings, discussions, etc. between the JIGT members. The primary source of the best business practices were the industry representatives. The following is a listing of those best business practices adopted by the JIGT and a brief discussion of the relative merits of that business practice.

1. *The NWTC will be managed as a single business unit.* A single person is in charge. In addition, all staff positions are provided by the Industry Joint Venture including the administrative and Systems Engineering Staff. The philosophy of a single business unit means that the organization is totally self-sufficient and does not have numerous layers of management to go through to make decisions.
2. *Provide cash flow consistent with projected spending plan.* Since it is envisioned that the Government will fund the majority of the capital cost of the program, the funds will be provided through the Congressional Appropriation process. This dictates that special provisions need to be adhered to so that the planned funding is not reduced after the program is started (i. e., Congress will not reduce the planned out year appropriations). Reductions in program funding would result in programmatic delays which would most likely result in increased program cost, litigation between the Industry Joint Venture and suppliers and possibly between the Industry Joint Venture and the Government. This is a critical assumption in that Congress must agree to a funding profile for the next eight years. Having reliable funding means the program can proceed with focus on executing this fast-track effort without diverting attention to the never ending "what if" and real funding profile changes.
3. *Use of design/build and Concurrent Engineering.* This activity means that parallel design and construction activities will be occurring. This increases the technical risk for the program but it provides for a reduced overall program schedule. In addition, concurrency allows for proper ordering of long lead materials before all the final decisions are made and thus reduces the schedule duration.
4. *Use of Integrated Product Development.* Integrated Product Development is a philosophy where the potential fabricators or constructors are contacted during the design process. This may entail the use of multiple fabricators or constructors to ensure competition as well as to ensure access to a wide range of ideas. When the design is sufficiently advanced so that fundamental changes are no longer anticipated, the fabricators or constructors are contacted with the idea of providing them with a pre-bid package. The fabricators and constructors that are typically contacted are those that are anticipated as being prime candidates for contracting. They can be put under contract or they may not be, this is situation dependent. The fabricators and constructors then provide input to the designers as to cost effective approaches to accomplish the end product. This allows the fabricators and constructors to be preparing their bid while the final design is progressing. In addition the interaction between the final fabricators and constructors and the design staff allows incorporation of bidder ideas and solutions and also prevents over-specification. Integrated Product Development increases the level of confidence in the constructability of the system. The fabricators and

constructors will then negotiate a fixed price contract at the conclusion of the final design. This would also eliminate a long procurement cycle and any potential design revisions to accommodate a particular fabricators methods.

5. *Use a streamlined procurement process.* This is one of the fundamental benefits of the Best Business Practice approach. This allows the Industry Joint Venture to use reputable suppliers and contractors who can deliver the product when needed. One mechanism to expedite the procurement process is to use pre-qualified bidders. Another method is to use the Integrated Product Development approach.
6. *Mature the design and validate requirements through preliminary design before finalizing the cost and schedule.* The Boeing Company attempted this approach with their Wind Tunnel Project. This ensures the fundamental engineering analyses and studies have been performed and the proper risk reductions have been performed prior to finalizing the program budget and schedule.
7. *Use contract incentives as appropriate.* People and organizations usually respond better to rewards than to punishments. Providing a challenge with a tangible reward is a good motivator.
8. *Component/subsystem validation and inspection is conducted by the supplier.* This reduces the number of inspection personnel for everyone; Government, Industry Joint Venture, Prime Contractor, and Supplier. This is a double-edged sword. Because by doing this the Industry Joint Venture would be willing to litigate to achieve requirements.
9. *Single Point Oversight.* The acquisition project team (Industry Joint Venture) stays focused on the NWTC project by not having its energy and time depleted by multiple layers of management reviews and fragmented oversight and direction.

## **2.4 An Alternative Consortium Model - Phased Consortium Approach**

The JIGT Phased Consortium Model addresses three key issues raised with regard to the Consortium Model.

1. How do you obtain Government input and expertise in the Design process?
2. How do you mitigate the risk to both the Government and the Industry Joint Venture?
3. How do you minimize the schedule impact of the formation of the Industry Joint Venture and Government Contract?

The Phased Consortium Model provides a means of initiating in parallel with the procurement of the Industry Joint Venture, the activities vital to the successful start

of the NWTC. The Phased Consortium Model approach provides a means for Government and Industry participation in the development of the value engineering and risk reduction approaches during the study and preliminary design phase. The NWTC design effort is led by the Government until approximately the 30% design level. The design has a reasonable time frame to mature while providing a means for validating the requirements. In addition, the program cost and schedule can be matured with a commensurate reduction in the overall program risk. The Phased Consortium approach also for the timely start of studies and preliminary design and provides up to 18 months for the creation of the Industry Joint Venture and contracts with the Government without impact to the initiation of the project.

#### **2.4.1 Phase 1 - Risk Reduction**

The Phase 1 Design Team is led by the Government with participation from representatives of Industry (via Memorandums of Understanding - MOU's). The Phase 1 design team has the responsibility for initiating the studies and the preliminary design and with the Government providing the required oversight of the preliminary design up to the 30% level. The Government contracts with A/E firms to perform studies and preliminary design. The work is performed either at distributed locations with electronic and video linkage or at a single location with management and systems engineering representatives co-located and the design efforts performed at the parent offices.

#### **2.4.2 Phase 2 Final Design and Construction and Phase 3 Activation and Operation**

The Phase 2 and Phase 3 of the alternate Consortium Model modify the Boeing Proposed Consortium Model. Contracting to the Industry Joint Venture is performed by a Fixed Price Incentive contract. The Government shares cost with Industry (undetermined share ratio). Novation of the design contract to the Industry Joint Venture for design completion is possible, or the Industry Joint Venture can negotiate a final design contract.

The primary issue associated with the Phased Consortium Approach is industry will be given a Fixed Price contract on a predetermined scope of work and predetermined engineering solution to the problem. This will minimize the amount of performance trades that could be performed by the Industry Joint Venture to possibly reduce the cost. However, by involving the industry representatives in the Phase 1 part of the activity, this concern can be mitigated.

#### **2.5 Program Staffing**

The Government Program Office envisioned for the Consortium Model will be staffed only by Civil Service Employees. Support Service Contractor personnel will not be involved in the Program Office. Determination of the required level of staffing was not part of the JIGT's charter. For purposes of determining the

program budget, the following assumptions were incorporated: (1) Civil Service salaries were not charged to the program budget, and (2) travel funds were provided from the "normal" NASA fund sources (i. e., from the travel budget of the center or headquarters unit where the program office is located) and were not charged to the program budget.

The Program Office assumed for the Consortium Model was different from the assumption for the baseline FSO Government Program Office. The FSO Government Program Office performed the program management activities as well as the Systems Engineering function. It was staffed with approximately 119 personnel - 25 civil service employees and 94 support service contractor personnel. The savings realized with the Consortium model for the Government Program Office versus the FSO Baseline Government Program Office are: (1) No contract employees saves \$98M and (2) No travel budget saves \$9.7M. These "savings" are only apparent savings because the scope of work covered in the FSO estimate must be accomplished. Therefore, the burden still exists to fund these tasks, but the staff to accomplish them will be provided by other sources.

## **2.6 Revisions to the Program Management WBS element (WBS 8000)**

Changes made in the estimate for Program Management for the NWTC were made to reflect an acquisition model where the Industry Joint Venture of U.S. Aerospace Industries provides the personnel and contracts with other industries to design and build the NWTC. The role of Government is to provide oversight and serve as the conduit to the Executive Branch for obtaining funding from the Congress. Noted below are detailed discussions of the changes made in the WBS 8000 category as a result of the JIGT activity.

**8100 Program Management:** Based upon discussions with Boeing, McDonnell Douglas, and General Electric; application of "Best Business Practices" allows the size of the management staff to be reduced from the 119 people in the baseline Concept D-Option 5 estimate to 80 people. This plus the reduced schedule (9.5 years to 8 years) reduces the estimate for Program Management from \$74.8M, to \$52M. The sub-element of Operator Training was reduced from \$21 Million to \$2.8 Million which eliminated a double booking of personnel wages between this element and the activation/calibration efforts in the WBS 3000, 4000, and 5000 categories. The \$15.4M identified as Maintenance and Operation Support is a reduction from \$25.74M and reflects the practice of accomplishing the majority of this type of work under warranties for equipment between its acceptance and the NWTC becoming fully operational.

**8700 Field Indirect:** No change was made in this estimate. The value of \$68.43M was provided by industry (Bechtel) as the cost of the "Trailer People" for a construction job of this magnitude.

**Government Program Office:** At the direction of the NWTC Program Manager, all staffing for the Government office is assumed to be provided outside the authorization and appropriation for the NWTC. Therefore, the estimate for providing travel and support services contract personnel was eliminated. The cost for buying the computer system for the systems engineering and management information system data base is contained in WBS 2000 leaving \$25.4M of this "adder" to be included in WBS 8000. This estimate covers the hiring of technical consultants to address specific issues during the design, construction, and activation of the NWTC; the hiring of third party reviewers (examples are the National Research Council, Aeronautics and Space Engineering Board, and other high level independent groups); performing significant work on environmental impact/assessments at multiple sites, and the maintenance of the technical and management data base computer systems during the life of this acquisition.

## **2.7 Consortium Cost Adders Used**

Cost adders are cost elements applied to the cost estimate below the Construction Estimate level to produce a total Construction Budget Estimate. This means all of the base cost estimates, including risk, for each major WBS category (x000 level) have been determined. The adders then are typically multipliers to the elements above it.

It was assumed that the contract type used by the Industry Joint Venture will be a Fixed Price Incentive type of contract. The magnitude of the available incentive has not yet been determined. It is intended that the incentives be contained within the estimated costs such that they are derived from value engineering and other cost saving measures.

Incentive award will be determined based on meeting the performance requirements for a cost below the Target Cost. The Target Cost is established at the System Design Review (approximately 25 to 30% design completion level). A Ceiling Cost is an integral part of the contract. The Ceiling Cost will be established when the Program is approved and is based upon the budgetary estimates. (The legitimacy of this approach with a Fixed Price Incentive type of contract is uncertain.) The Fixed Price Contract will be established as the Target Cost at the System Design Review. Prior to that, the contract will be a Cost Reimbursable type of contract. Incentives for providing a project cost below the Target Cost, will be amortized over the life of the facility.

### **Cost Estimate Baseline for Adders:**

1. All WBS element cost estimates are for installed prices from a contractor or supplier. The cost estimate includes the contractor's or supplier's markups including sales tax (6% of materials, equipment, rentals), and profit (typically ranges from 5 to 10%).

2. Each WBS element construction cost estimate includes an assessment of risk as a percentage of the engineering estimate. The risk accounts for cost estimating accuracy assessed at the lowest level of the WBS estimate.
3. Design contractors are responsible for correcting errors and omissions.
4. Field indirect costs are included in WBS 8000 category.
5. The Engineering level estimate is in July 1993 dollars so as to be consistent with the original FSO cost estimates for direct comparisons. This means the escalation to the midpoint of construction is taken from July 1993 rather than from February 1994.

JIGT Cost Adders:

1. Profit for the Industry Joint Venture acting as the Prime Contractor has been assumed to be zero because it is a "not for profit" entity.
2. Bond premium for sub-contractor efforts is assumed to be 0.8% of the construction cost.
3. Escalation is to the mid-point of construction rather than escalating the uncosted balance to the year in which it is costed. Escalating to the midpoint of construction is a standard Government method of handling escalation that does not require an excessive amount of effort to determine when all of the work will be performed and costed accordingly. Escalation to the midpoint of construction is typically somewhat conservative. The escalation rate used was a uniform 3.5% per year. Escalation was taken from July 1993 to July 1999. It should be noted that current economic trends may not support a long term annual escalation rate of 3.5%. If the actual rate of inflation exceeds 3.5%, then the available project contingency will be reduced.
4. This increases the contingency from the 10% found in the FSO Final Report dated December 1993 and matches the 20% contingency found in the Boeing cost estimate. The 20% contingency includes 10% associated with Government directed changes and additional effort required in areas where the Government is responsible for errors in the requirements or design. The remaining 10% is to cover the Contractor's risk that is normally charged against the profit of the contractor(s). In the consortium approach, the Industry Joint Venture is the prime contractor and does not have profit or assets to cover liability. The cost estimate by the JIGT included profit for the contractor's installation hardware, but not for a prime contractor.
5. Supervision, Inspection, and Engineering Services (SIES) has been assumed at a total of 8%. Construction Management accounts for 3/4 of the SIES adder (or 6%), while the Engineering Support Services account for the remaining 2%.

### **3. Program Schedule**

A detailed program schedule was developed assuming "Best Business Practices." This schedule was iterated a number of times to ensure all of the necessary elements were included.

#### **3.1 Schedule Description and Assumptions**

##### Schedule Assumptions:

1. Joint Venture formation is a part of the schedule
2. Project Start assumed to be 1 April 1994 (Year 0 on the Engineering Schedule)
3. Concurrent Engineering & Construction used to accelerate the tunnel construction schedule. Concurrent engineering/construction used for all major project activities.
4. Funding is available when required.
5. Expedited procurement cycles for urgent studies (1 month), tunnel design (3 months) and site design contracts (4 months)
6. A single Design Agent will be used for Preliminary and Detail Design of the wind tunnels and the auxiliary process systems (i. e., no serial procurement activity between Preliminary and Detailed Design)
7. Site selected in 8 months from project start. Total site selection, writing the Environmental Impact Statement(s), and the permitting process is 18 months.
8. Use preliminary specifications to award wind tunnel shells and drive systems design/build contracts
9. Build-to-print contracts for wind tunnel internal components and auxiliary equipment
10. Industry practices are adhered to when procuring design services, construction, and material contracts.
11. Construction will take place on a "green field" site (no existing on-site infrastructure)
12. Preliminary Design starts prior to Congress fully funding the project
13. A single Design Agent will design the buildings and develop the Master Site Plan
14. Project Complete task left free to shift (no "hard target" completion date), the resulting schedule has no risk mitigation time (i. e., no slack on the critical path).
15. Activity durations are in average working weeks (4.33 weeks per month, 5 day work week)
16. The calendar incorporates all Federal holidays as non-working days
17. Start-to-Start and/or Finish-to-Finish relationships (with lag) between high-level tasks were used as a quick substitute for developing a large PERT network of detailed tasks
18. Sub-system, system and integrated systems checkouts are included in the program schedule

19. Multiple shifts and planned overtime assumed only for integrated systems checkouts and calibrations.
20. Calibration durations reduced to 3 months for LSWT and 4 months for TSWT

#### Schedule Description:

The schedule was developed using a PERT network with predecessor and successor logic. The schedule consists of 258 tasks.

### **3.2 Schedule Development Process**

The schedule was developed in three distinct phases. During each phase, the network logic and activity durations were assessed and the schedule updated. The head of the schedule team coordinated all inputs and review comments in order to prevent duplication or usurpation of previous efforts. The critical path was monitored continuously. However, it was not mandated that the project have a defined duration. If it was shown that the project duration was extending, then the network logic was reassessed to see if there was a different or better way of procuring the element or performing the task that might help minimize the impact on the critical path.

#### Phase 1 - Initial Schedule Development

1. Initial network logic and preliminary durations defined by a sub-group of the schedule team. Total of 162 activities defined and linked.
2. Identified and groomed the resulting critical path
3. Conducted an initial schedule review with the JIGT participants.
4. Incorporated the recommended changes to durations, descriptions and logical dependencies. Added 16 new tasks and the appropriate logical dependencies (178 total tasks).
5. Identified and groomed the resulting critical path

#### Phase 2 - Subsequent Schedule Development

6. Technical teams reviewed the schedule after the initial review. Added 52 additional activities and the appropriate logical dependencies (230 total tasks)
7. The schedule was then updated to incorporate the NWTC Concept D-5 Work Breakdown Structure assignments to each task so that all work elements were incorporated and also so that initial planning for cost profile could be considered.
8. Conducted a detailed review of the WBS assignments with Technical team members. Incorporated the recommended changes to durations, descriptions and logical dependencies.
9. Identified and groomed a more accurate critical path

### Phase 3 - Revisions After Presentation to the NWTC Program Manager:

10. Added cost values to the appropriate tasks to devise a time-phased spending profile
11. Incorporated the Program Startup logic including the Industry Joint Venture formation. After reviews, added 33 tasks and the appropriate logical dependencies (258 total tasks)

### **3.3 Schedule Results**

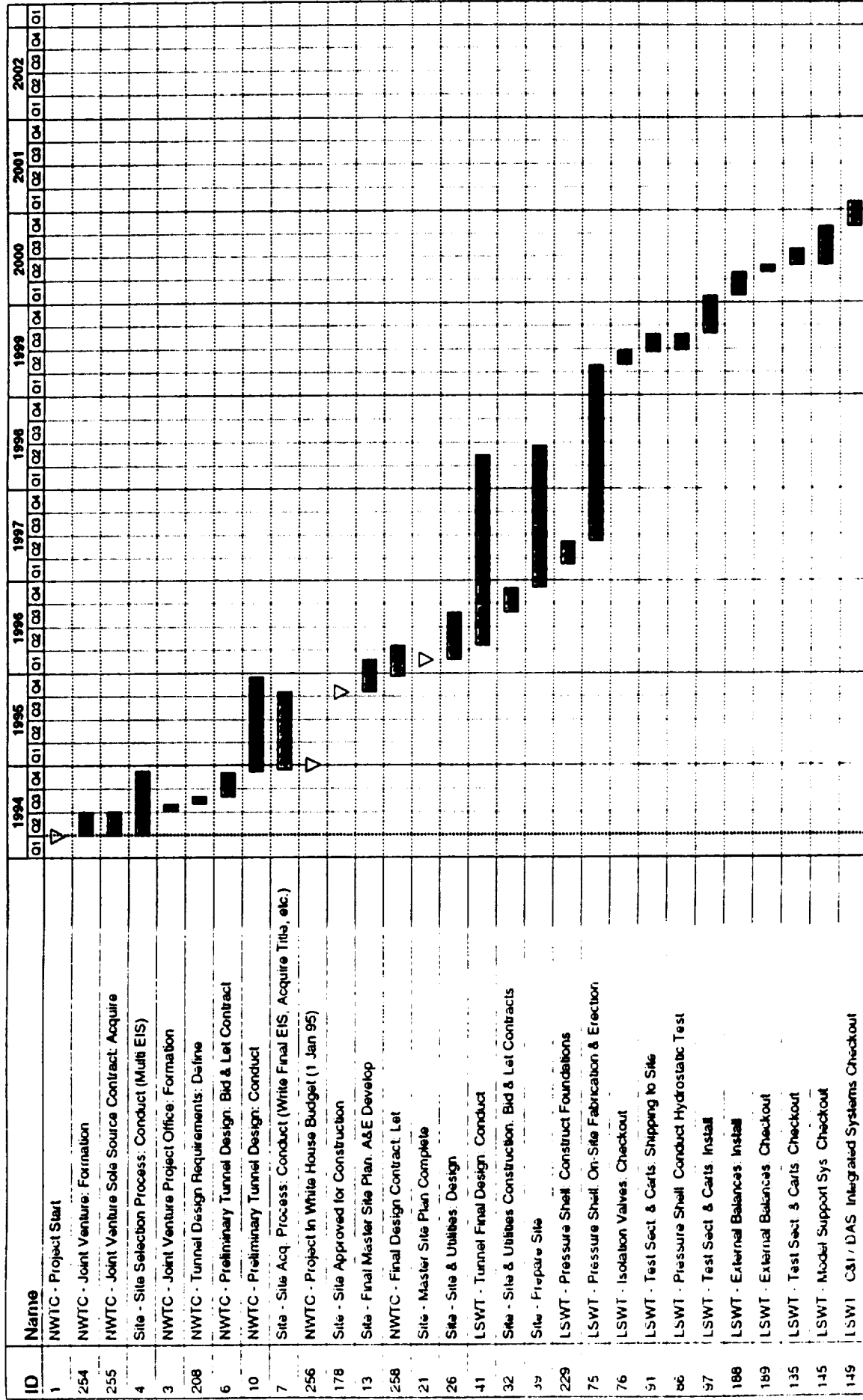
1. Total Program Duration is 8 Years from Start of 1 April 1994. Program Completion is April 2002
2. Critical Path to Program Completion is through the LSWT Pressure Shell. Note that the drive system is only a few months behind the pressure shell from being on the critical path.
3. Urgent studies must begin April 1994
4. Preliminary design begins October 1994
5. Site selection required January 1995
6. Site specific design begins January 1995
7. Shell erection begins June 1997
8. All designs complete May 1998
9. LSWT drive system delivered May 1998
10. Midpoint of construction is July 1999
11. TSWT is ready for customer use in March 2002
12. LSWT is ready for customer use in April 2002
13. Hydrostatic tests for shells establishes constraints for many activities
14. Zero slack in 8-year schedule

Figures included are the Summary Program Schedule - Figure 3.1 and the Schedule for the Critical Path elements - Figure 3.2. Schedules for the Milestone elements and the schedule for all elements are provided in Appendix 4. The Task Sheet that lists all elements and the associated information (e. g., start/finish dates, durations, predecessors, etc.) are also provided in Appendix 4.

[illegible]

Figure 3.2: NATIONAL WIND TUNNEL COMPLEX

Critical Path  
(Calendar Years)



[illegible]

### **3.4 Schedule Acceleration Techniques**

Provided below are the methods identified for accelerating the program schedule. It should be noted that these techniques have a significant impact on the program schedule the earlier in the program they are exercised. If these techniques are exercised later in the program's timeline, they may have little effect.

#### **Methods During the Organizational Phase**

1. Establish operating informal Joint Venture Reporting to NASA Administrator and Corporate President level
2. Dedicated staff including Acquisition staff and Legal staff
3. Adopt Best Business Practices
4. Detailed Project Planning Phase
5. Release of design funds to Program Office
6. Early site selection
7. Co-location of Joint Venture at site
8. Multiple Environmental Impact Statements
9. Establish multiple A/E contracts

#### **Methods During the Design Phase**

1. Overtime
2. Schedule-driven awards such as early order of long lead items and the construction of pressure shell foundation on critical path
3. Selective bidders' list for design/build items. Multiple awards for design phase
4. Parallel design of wind tunnel shell and internals
5. Verification of systems level requirements
6. Concurrent engineering
7. Initiate design in April 1994
8. Industry Joint Venture and A/E systems engineers co located at the site.

#### **Methods During Construction Phase**

1. Schedule-driven awards
2. Incentive contracts for cost and schedule reduction
3. Maintenance and operations contract for all completed systems. This is required because items will be accepted prior to total program completion
4. Industry Joint Venture and A/E systems engineers co located at the site.

#### **Methods During Checkout Phase**

1. Multiple shifts
2. Overtime
3. Systems Engineering and contractor support for redesign, modification, and repair.

#### 4. Technical and Cost Descriptions

##### 4.1 Comparison of Concept A: FSO Cost Estimate and The Boeing Company Estimate

The Boeing Company had previously initiated a program to develop a new wind tunnel complex. This complex was to provide a test facility that focused on providing high Reynolds number test capability and an extremely productive test facility. As with all commercial ventures, the initial set of requirements were the upper limit goals that could be negotiated if needed in order to provide overall program cost relief. The Boeing Company had conceptual design contracts with the major A/E firms that are in the business of designing wind tunnels (Fluidyne, Sverdrup, and DSMA). The purpose of the conceptual design contracts was to reduce the overall program risk as well as to mature the design to the point where a reasonable cost and schedule estimate could be established.

In February 1992, The Boeing Company terminated the project. During the spring and summer of 1993, the Facilities Study Office conducted an assessment of the cost, scope, and schedule of the Boeing Wind Tunnel program for the Aero-Facilities Task Group. Additional facility concepts were also assessed. The results were published in the FSO Final Report dated December 1993.

The Boeing Company had provided a cost estimate of \$958M (in 1991 dollars). This estimate was escalated two years at 3.5% per year so the Boeing costs were in the same year as the FSO cost estimate. The comparison results were:

	<u>Duration</u>	<u>Cost</u>
The Boeing Co.	5 Years	\$1,026M (\$958M in 1991\$)
FSO	9.5 Years	\$2,316M

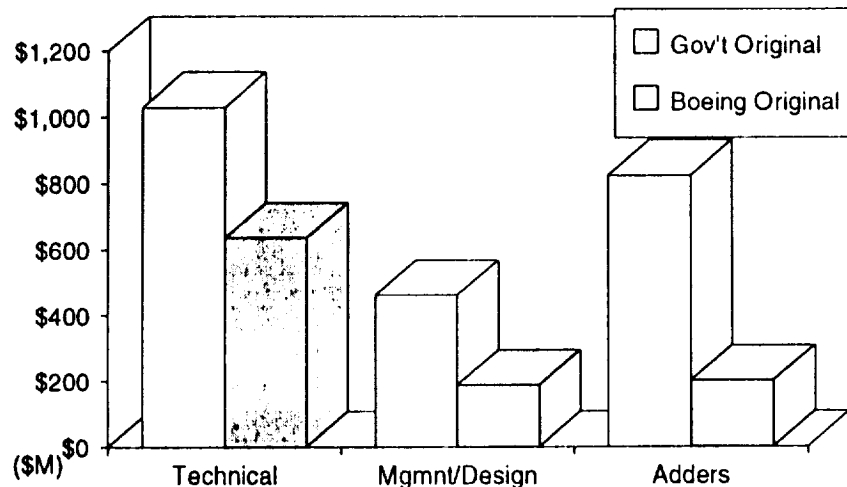
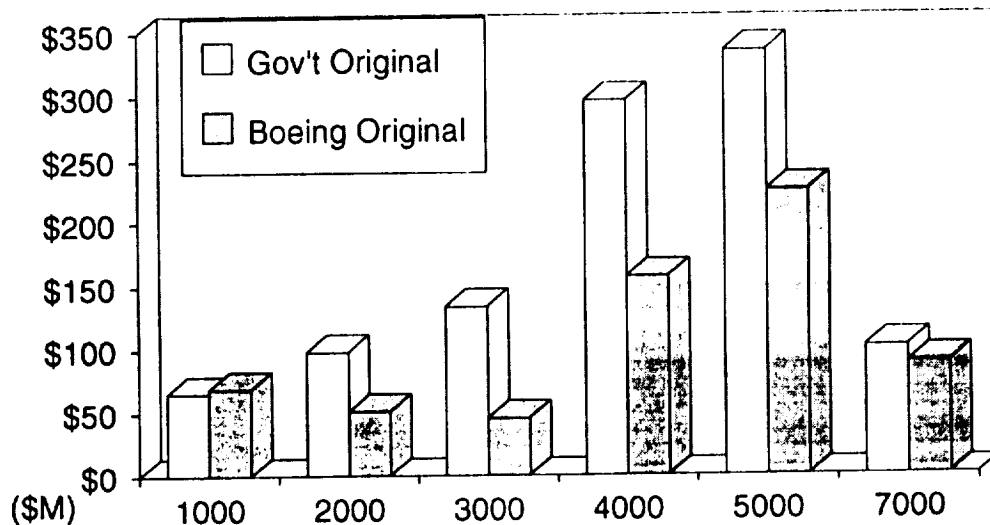


Figure 4.1 Comparison of FSO and Boeing Cost for Concept A

Numerous discussions were held prior to the JIGT activity to understand the significant differences in the cost and schedule for the FSO Concept A (FSO's understanding of the scope of the Boeing Wind Tunnel Program) and the final Boeing cost estimate. Large cost differences are apparent as seen in Figure 4.1 for all categories. The "Technical" category in Figure 4.1 consists of the WBS 1000 through 7000 categories with the Risk included. The "Mgmt/Design" category includes the WBS 8000 category, the Government Project Management category, PER, Studies, and Design categories. The "Adders" category includes the Profit, Bond, Escalation, Contingency, and Supervision, Inspection, and Engineering Services (SIES) elements. Common understanding of the differences between the Boeing cost estimate and the FSO Concept A cost estimate was necessary before a reasonable assessment of the cost for the National Consensus Requirements Solution (Concept D - Option 5) could be made. The results and findings of the discussions are provided below. It is noted that resolution of the management and business practices (i. e., management and adders categories on Figure 4-1) was not attempted by the Technical Team. The resolution of that category was discussed as part of the Consortium approach and Best Business Practices.

The primary purpose of the review was to determine the differences in technical scope (WBS 1000 - 7000), cost, cost estimating methodology, and risk assessment between the Boeing Wind Tunnel Complex and the FSO Concept A, and to reach a consensus agreement on the Joint Industry Government Cost and Scope for Concept A. The review focused on the areas of largest cost disagreement. Figure 4.2 illustrates the areas of greatest technical cost difference.



**Figure 4-2: Comparison of Concept A Technical Costs by WBS Category**

General discussions were held beginning with the two wind tunnels and then branching out to the support auxiliary process systems, infrastructure, buildings, etc. The discussions focused on requirements definition and solution approach. The primary intention was to understand the differences in the solution approach between the Boeing and FSO cost estimates and the basis (quotes, bottoms up estimate, design, engineering judgment, etc.) for both cost estimates. Insufficient technical information on the Boeing Wind Tunnel configuration was available to perform a detailed technical review. The technical information provided by Boeing consisted of the personal recollections of the review personnel, the information previously provided (WBS Dictionary, preliminary air line drawing from DSMA for the Low Speed Wind Tunnel, program management presentations, etc. ), and the descriptive information contained within the cost estimate.

Consensus on the scope and cost for Concept A among the JIGT members was not attained. With no new technical information provided, the JIGT felt that there was no basis to make changes in the technical approach or cost. Consequently, the focus of the review was shifted to "obtain an understanding of the differences between the costs and the cost estimating methodology."

#### **4.1.1 Discussion of Differences in the Technical Content**

##### **Prior to the review:**

- Significant cost and schedule differences existed
- Significant scope (i. e., technical approach) differences existed
- Fundamental business/procurement practice differences existed

##### **During the review:**

- Concluded that selected fundamental scope differences did exist
- Concluded that both estimates had either oversights, underscopes, or excessive conservatism that needed to be corrected
- Concluded that cost differences did exist - in unit costs, quoted costs, and risk costs

##### **Scope Differences:**

1. Low Speed Wind Tunnel Pressure Shell - 140% larger volume for FSO Shell - Boeing used 1.3 Million Cubic Feet while the FSO Circuit was 1.8 Million Cubic Feet internal volume. The FSO volume was based on the DSMA circuit layout provided to the FSO by Boeing. The circuit layout used by Boeing was not available.
2. Tunnel Support Structure - FSO assumed structural steel to grade for both tunnels while Boeing had concrete piers providing structural support much higher with a much lower amount of steel (\$10.5 M total difference for both tunnels).

3. Buildings - Boeing - wind tunnel enclosure buildings replaced with sunshades while the FSO estimate included the wind tunnel enclosure buildings.
4. Auxiliaries - Low Pressure Air System 2/3 less compressor capacity for the Boeing system than for the FSO system. Quantities and sizes of piping were less for Boeing.
5. Instrumentation - Boeing provided tunnel instrumentation from existing hardware while the FSO assumed that this hardware would be provided with the project.
6. Testing and Validation - Boeing estimated staffing and utilities required, while FSO assumed a percent of the capital cost. The Boeing estimate did not provide for tunnel calibration. This expense was to be born by early tunnel users.
7. Model Access - Boeing estimated a large model access door while the FSO used the Rolling Plenum Concept.

#### Cost Estimating Methodology Differences:

1. Boeing used conceptual design contracts to mature the design and finalize the design approach before the final budget was established and presented to their funding source (The Boeing Company Board of Directors). The FSO was requested to develop budgetary cost estimates without the opportunity to mature concepts or finalize approaches. FSO developed cost estimates based on parametric cost estimating as well as some "bottoms-up" estimating. Sketches were developed to define a system configuration. Engineering judgment was applied to further define costs to develop a budget that was viewed as a not to exceed budget.
2. Boeing's costs were based on trading performance, productivity, and cost against each other. FSO viewed requirements as firm and non-negotiable and no trades were considered.
3. Risk: FSO considered risk as a separate definable quantity, while Boeing considered risk as an element of profit.

#### Cost Differences:

1. Risk - The largest cost difference is in the assessment of risk. Boeing felt risk was significantly lower than did FSO (say 5-10% versus 26%). The Concept A design was considered more mature by Boeing than the FSO. The Boeing project was canceled only two weeks prior to signing fixed price contracts for the tunnel internals. (Note: Boeing had not received a bid price from their potential contractors.) Also Bechtel was under a cost reimbursable contract. Therefore, at least for the tunnel internals (for both tunnels), which represent 22% of the total program cost (i. e., with all adders considered)+, this could be true. However, since the FSO was not afforded the opportunity to review the technical detail that might be available for the tunnel internals, or other project designs, it was not possible to revise the risk assessments.

2. Boeing's building unit costs were consistently 5-10% less than FSO's. If risk was not considered in the FSO cost, then this is the only real difference in the building cost
3. Pressure Shells - installed unit cost - Boeing \$4.55/lb., FSO \$4.50/lb. Good agreement on the unit cost, but a large difference in the calculated pressure shell weights.
4. Tunnel Motor and Motor Controls Unit Costs - Good Agreement for LSWT drive system, however, Boeing put the cost for the compressor shell with the pressure shell versus with the drive system. Boeing's unit cost was approximately 1/2 FSO's for TSWT drive system. The FSO used the same methodologies for developing the cost estimates for both the LSWT and TSWT drive systems (unit costs, etc.).
5. Model Carts - unresolved factor of 2 difference in cart costs
6. Isolation Valves - unresolved factor of 7 difference in the isolation valve costs.

#### **4.1.2 Discoveries Made and Changes Incorporated**

1. Boeing increased weight of LSWT shell to account for differences in shell weight and volume. Boeing shell cost increased by about factor of 2.
2. The FSO cost estimate kept the two tunnel enclosure buildings but deleted three 300 ton cranes and reduced the capacity of the remaining 300 ton crane to be 100 ton capacity. This change was for both wind tunnel enclosure buildings. Overall change was about \$4M reduction per building.
3. FSO eliminated the Open Jet Test Section from Concept A (\$3.6M)
4. Boeing increased the low pressure air system capacity to be consistent with the Bechtel WBS description. This change was then consistent with the FSO system and cost.
5. FSO reduced the facility cooling system (WBS 3400) design heat load by 33% with a commensurate reduction in the cost for the cooling tower and pumps. This reflected a more realistic design heat load condition rather than designing for the total connected heat load.
6. FSO eliminated external balance calibrator cost in WBS 7190 because the cost was included with the external balances (\$5M)
7. Boeing added the cost for new instrumentation to their cost estimate (\$21M increase).
8. The FSO Cost for test, validation, and calibration for the Auxiliaries, LSWT, and TSWT was revised to reflect an estimated staffing, utility costs, and consumables cost.
9. The area of model access was another area of significant difference. Provided here is a brief discussion of how that issue was resolved.

FSO used the rolling plenum concept. Boeing was using a large model access door to withdraw the test section carts. The differences in the overall capital cost though are negligible.

#### Boeing Door

Seals  
Door  
Latching  
Door Mechanism  
Handling Element  
Cost = \$2,310K

Pressure Shell-1900 Tons  
Cost = \$17,300 K  
Total = \$19,610K

#### FSO Rolling Plenum

Seals  
Internal/External Structure  
Latching  
Drive System  
Pressure Shell  
Cost = \$6,506K

Tie Structure-1360 Tons  
Cost = \$12,200K  
Total = \$18,706K

*Appears as if both concepts cost about the same at \$20 Million.*

10. TSWT Plenum Evacuation System - Both FSO and Boeing included Plenum Evacuation Systems (PES). However, the PES developed by the FSO required approximately 100,000 horsepower, while the Boeing PES required 45,000 horsepower. Insufficient technical information was available to ascertain the mass flow rate or the compression ratio of the Boeing PES, for comparison with the FSO system. Although the costs compared favorably, Boeing and the FSO were estimating two different systems. No resolution was achieved.

#### **4.1.3 Scope and Cost Differences Still Existing Between The Boeing Wind Tunnel Complex And FSO Concept A After the Review**

1. General:
  - Risk assessment is still significantly different. Note that the Boeing costs include risk whereas the WBS thousand level costs shown for the FSO do not include risk.
2. WBS 1000 - Site and Infrastructure:
  - No reason known for the differences.
3. WBS 2000 - Buildings:
  - Unit costs are approximately 5-10% different (Boeing is lower).
4. WBS 3000 - Auxiliary Process Systems:
  - If the revisions made by Boeing remain, then no significant differences exist.
5. WBS 4000 - Low Speed Wind Tunnel:
  - FSO still has the full tunnel enclosure
  - Differences in the tunnel shell cost still exist, \$20M
  - Differences in cost for test carts
  - Differences in cost for isolation valves

- Differences for costs for internals due to approach differences (e.g., turning vanes)
6. WBS 5000 - Transonic Wind Tunnel:
- FSO still has the full tunnel enclosure
  - Unresolved \$10M difference in the TSWT Pressure shell
  - Differences in the weight and complexity for the tunnel isolation valves
  - Differences in cost for test carts
  - Significant difference in the cost for the drive system
7. WBS 7000 - Operations:
- Variations in costs for instrumentation and the Airflow Calibration Lab.
  - Boeing internal procurement policy mandates procurement of all computers from the Boeing Computer Systems Group. Therefore, the cost for the electronics for Boeing was about \$20M higher than the FSO cost.

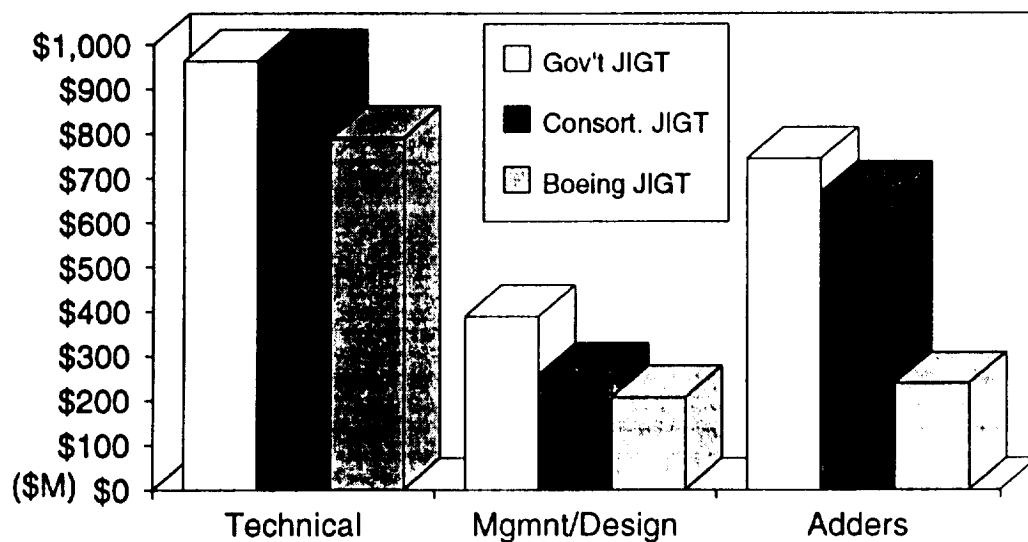
#### **4.1.4 Cost Estimate Comparisons and Results**

Provided below are the summary cost estimate results for Concept A. The results provided are comparisons at the WBS x000 level between the FSO Concept A and the Boeing Wind Tunnel Program both before the JIGT review and after the JIGT review. Note that the costs for the taxes, estimators allowance, and shipping have been incorporated into all of the Boeing costs whereas in previous documentation these cost elements were shown as separate items.

**Table 1: Concept A Cost Comparison Results**  
(All Dollars in Thousands)

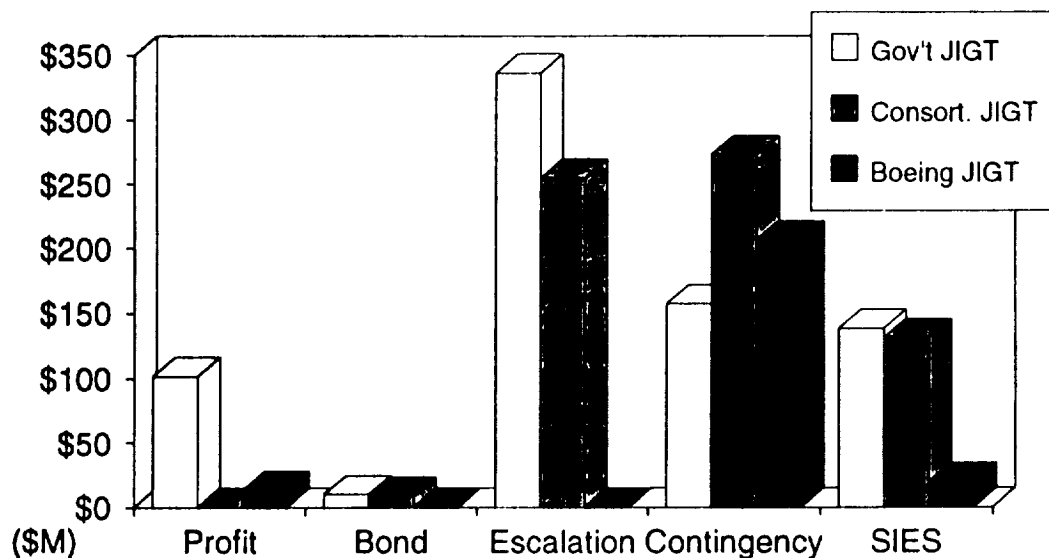
WBS	Description	Gov't (8/3/93)	Gov't JIGT (2/25/94)	Consortium JIGT (2/25/94)	Boeing Co. Original	Boeing Co. JIGT (2/25/94)
1000	Site & Infrastructure	\$56,354	\$55,590	\$55,590	\$68,570	\$68,570
2000	Buildings	\$79,297	\$68,381	\$68,381	\$51,012	\$63,307
3000	Aux. Process Sys.	\$108,642	\$103,530	\$103,530	\$45,136	\$111,207
4000	LSWT	\$227,286	\$212,537	\$212,537	\$157,106	\$199,475
5000	TSWT	\$262,116	\$251,742	\$251,742	\$225,216	\$234,886
7000	Operations	\$82,279	\$78,493	\$78,493	\$89,004	\$112,905
8000	Mgmt. & Support	\$186,660	\$158,120	\$135,370	\$78,871	\$78,871
	Engineering Est.	\$1,002,634	\$928,393	\$905,643	\$714,915	\$869,221
	Risk	\$216,889	\$196,440	\$196,440	In Above	In Above
	Sub-Total	\$1,219,523	\$1,124,833	\$1,102,083	\$714,915	\$869,221
	Profit	\$121,953	\$112,843	\$0	\$10,738	\$12,973
	Bond	\$13,415	\$13,373	\$8,817	\$0	\$0
	Escalation	\$365,824	\$340,265	\$254,680	\$0	\$0
	Contingency	\$172,073	\$158,995	\$273,116	\$171,059	\$206,019
	Const. Mgmt (6%)	\$113,568	\$104,937	\$98,322	\$19,711	\$19,711
	Engr. Support (2%)	\$37,856	\$34,979	\$32,774	\$0	\$0
	Total Construction Budget	\$2,044,212	\$1,890,225	\$1,769,792	\$916,423	\$1,107,924
	PER	\$40,884	\$37,777	\$0	\$0	\$0
	Government PM	\$102,961	\$96,346	\$28,645	\$33,636	\$39,419
	Studies	\$38,523	\$11,460	\$8,660	\$0	\$0
	Design	\$89,592	\$82,665	\$82,665	\$76,297	\$88,769
	PROGRAM TOTAL	\$2,316,172	\$2,118,473	\$1,889,762	\$1,026,356	\$1,236,112

The comparisons for the JIGT cost estimates are provided in Figure 4.3. The Government JIGT cost estimate is the original FSO Concept A cost estimate upgraded to reflect the discoveries and changes made as discussed previously. The Consortium JIGT cost estimate is the Government JIGT cost estimate with the Consortium adders, management, and schedule philosophy incorporated. The Boeing JIGT cost is the original Boeing cost estimate revised to incorporate the discoveries and changes made as previously discussed.



**Figure 4-3: Comparison of Revised Concept A Cost Categories**

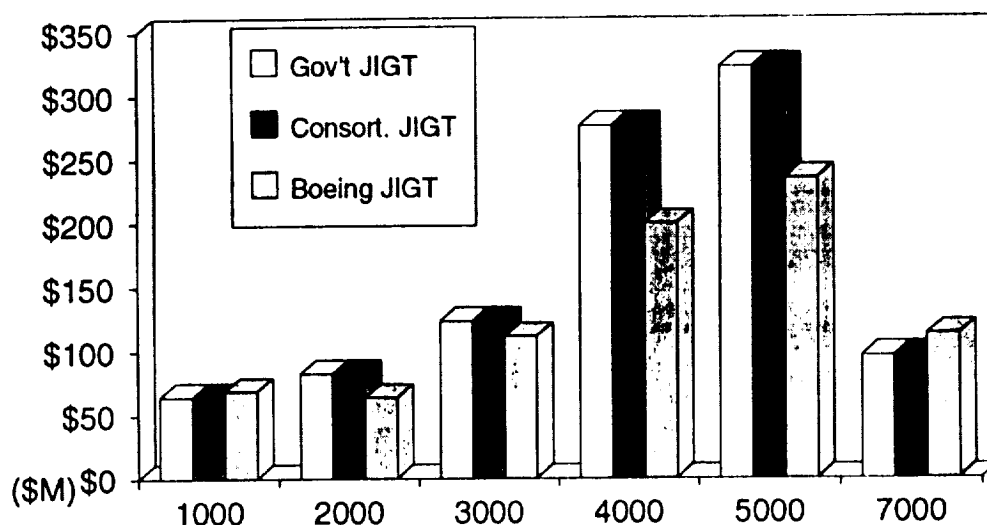
The largest area of difference that still exists is in the Adders category. This difference is highlighted in more detail in Figure 4.4. The technical differences are highlighted in Figure 4.5. The differences in the Management and Design category were not significant enough to warrant a more detailed examination.



**Figure 4.4: Comparison of Revised Adders Cost Categories**

As can be seen in Figure 4.4, the single largest element causing the differences between the Boeing cost estimate and the other two is the Escalation element. The Boeing cost estimate does not currently include Escalation, while the other two

include Escalation to the mid-point of construction. The next largest area of disagreement is in the cost associated with the Construction Management and Engineering Support Category (SIES category). This issue was left unresolved.



**Figure 4.5: Comparison of Revised Technical Cost Categories**

The differences in the Technical WBS elements are highlighted in Figure 4.5. The largest elements of disagreement are with the two wind tunnels - WBS 4000 and 5000. For the LSWT (WBS 4000) the largest areas of disagreement are the cost for the Test Section carts, the cost for the pressure shell, and the use of the Wind Tunnel building for the Consortium JIGT cost and only a sunshade for the Boeing JIGT cost. For the TSWT (WBS 5000) the largest areas of disagreement are the tunnel drive system, the tunnel internals, the cost for the pressure shell, and the use of the Wind Tunnel building for the Consortium JIGT cost and only a sunshade for the Boeing JIGT cost. These cost differences are accentuated by the disparity in risk assessment. The Consortium JIGT cost estimate has a risk value of 25% whereas the Boeing JIGT risk assessment while not determinable, was thought to be considerably less. The differences in the risk most likely account for the largest single contributor to the differences in the cost for the Technical category.

#### **4.2 Leverage of Concept A to Concept D, Option 5**

A review was held to explain how the fundamental parameters for the Concept D - Option 5 configuration were determined. The total systems approach was used to assess the impact of requirements changes from the Concept A configuration to the Concept D configuration. These changes included impacts on the site and infrastructure, on buildings, on the auxiliaries, interactions between the two tunnels, how the design might be impacted, etc.

The largest change occurred with the LSWT circuit as a result of the increase in the test section size. The test section area increased from 288 square feet to 432 square feet. The Concept A and Concept D configurations used the same contraction ratio. The scaling laws developed for the rest of the circuit were:

Linear dimensions scaled by square root of test section area ratio = 1.22

Shell surface area scales by the test section area ratio = 1.5

Shell weight (volume) scales by the (test section area ratio)<sup>3/2</sup> = 1.82

Drive Power (mass flow rate) scales by the test section area ratio = 1.5

The TSWT circuit was stretched to accommodate the additional stage(s) required for the compressor, flexible nozzle, and to add length for the flow development region.

All discoveries from the Concept A review were incorporated into the Concept D - Option 5 revisions. The cost scaling was applied to the FSO Concept A to obtain the JIGT Concept D - Option 5 Cost

The Concept D - Option 5 configuration that was used in the JIGT activity was the basic configuration that was described in the FSO Final Report dated December 1993. No configuration changes were made. Changes in selected features and/or quantities were made to the scope of the JIG Concept D - Option 5 from the FSO Concept D - Option 5. However, the fundamental performance requirements remained the same.

#### **4.2.1 Incorporated Changes**

Provided in this section is a detailed description of the changes made to the technical scope of the Concept D - Option 5 configuration. The National Consensus Requirements were not changed. The changes incorporated are sub-system or component performance requirements or solution approaches.

General Systematic changes include:

1. Revised the low pressure air system pumping capacity to take advantage of stored air. This affects the low pressure air system, cooling water system, and power distribution system.
2. Corrected the estimate to be consistent with the National Consensus Requirements for the model propulsion simulation requirements. This affects the high pressure air system, cooling water system, and the power distribution system.
3. Cleaned up the cost estimate to eliminate instances of double bookkeeping (TSWT carts and external balance calibrator), and initial oversights (TSWT flexible nozzle).

4. Reduced the amount of handling equipment in the tunnel enclosure buildings.
5. Revised the philosophy for determining the costs for test, validation, and calibration. The cost was determined using an estimated staff, expendables, utilities, etc., versus using a percent of the construction cost.
6. Revised the design point for the site cooling water system to reflect a more realistic condition. This impacts the cooling water system and the site layout.

Specific WBS categories that are affected by these changes are:

1. WBS 1000 - Site and Infrastructure:  
Yard Electrical Station Cost was reduced because one low pressure air compressor and one high pressure air compressor were deleted
2. WBS 2000 - Buildings:  
Risk was reduced to 20% from 25% for the Test Preparation/Control Buildings, Model Shop and Warehouse, and Wind Tunnel Pressurization/Vacuum Building
3. WBS 3000 - Auxiliary Process Systems:
  - a. Eliminated one low pressure air compressor and associated air dryer and air filters. The tunnel pressurization requirements can be met with four compressors and the specified 300 psig air storage.
  - b. Revised high pressure air system to be consistent with the current National Consensus Requirements for model propulsion simulations. Eliminated one high pressure air compressor, reduced the required capacity for the remaining compressor from 70 pps to 50 pps, eliminated one high pressure air dryer, reduced high pressure air storage from 7000 cubic feet to 6000 cubic feet, and reduced the high pressure air distribution line size from 10" to 8".
  - c. Revised the cooling system design point to be approximately 67% of the connected heat load versus 100% of the connected heat load. New design point has the following concurrent heat inputs: TSWT at 80% power ( $M = 0.8$  at 5 atm), TSWT PES at 80% power, LSWT at 67% power ( $M = 0.2$  at 5 atm), and auxiliary compressors at 25% power. Affected components are: a reduced cooling tower capacity, elimination of one cooling water pump, and a reduction in the main water distribution line size from 7 feet to 6 feet diameter.
  - d. Revised the auxiliary test and validation activity to be consistent with an assumed staffing level versus a percentage of the installed cost.
4. WBS 4000 - Low Speed Wind Tunnel:
  - a. Eliminated three 300 ton cranes and reduced the capacity of the remaining crane from 300 tons to 100 tons for the LSWT Enclosure building.
  - b. Reduced scaling of the turning vane size.

- c. Reduced the risk for the screens and honeycomb to 30% from 40%
- d. Reduced design cost of external balance
- e. Reduced design estimate for movable plenum and test section carts
- f. Re-evaluated and reduced the test, validation, and calibration costs
- 5. **WBS 5000 - Transonic Speed Wind Tunnel:**
  - a. Eliminated three 300 ton cranes and reduced the capacity of the remaining crane from 300 tons to 100 tons for the TSWT Enclosure building.
  - b. Increased cost of flexible nozzle (initial oversight)
  - c. Reduced cost of test section carts (double-bookkeeping)
  - d. Re-evaluated and reduced the test, validation, and calibration costs
- 6. **WBS 7000 - Operations:**
  - a. Deleted external balance calibrator - (double bookkeeping)
  - b. Minor reductions in all instrumentation and data acquisition costs.

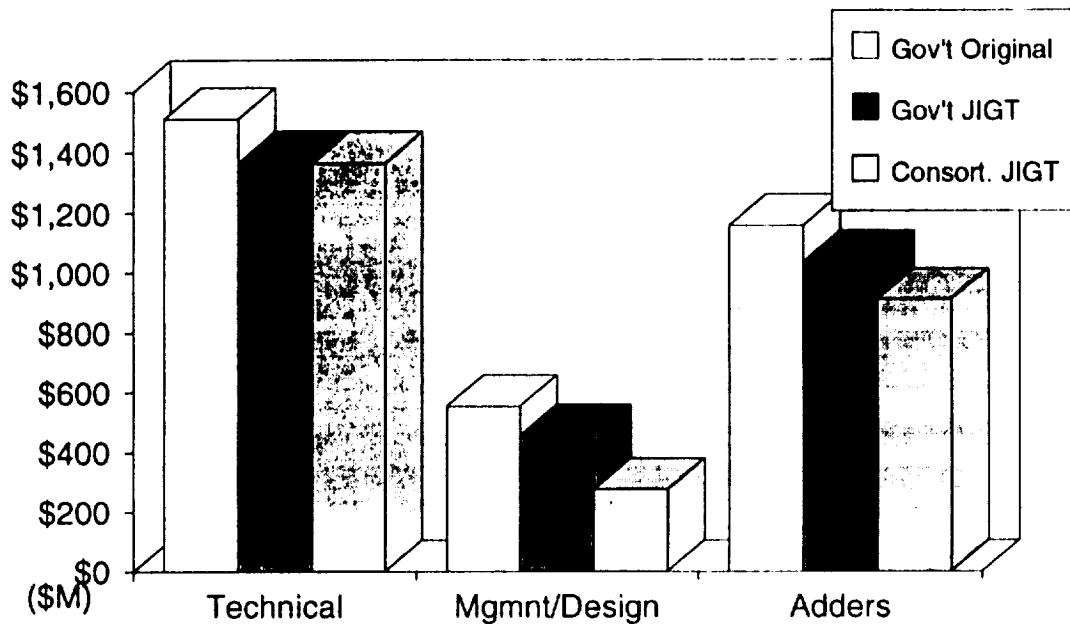
#### 4.2.2 Cost Estimate Changes

Provided in Table 2 are the cost comparisons at the WBS x000 level for the Concept D - Option 5 for the JIG cost versus the original FSO cost estimate.

**Table 2: Concept D-5 Cost Comparison Results**  
(All Dollars in Thousands)

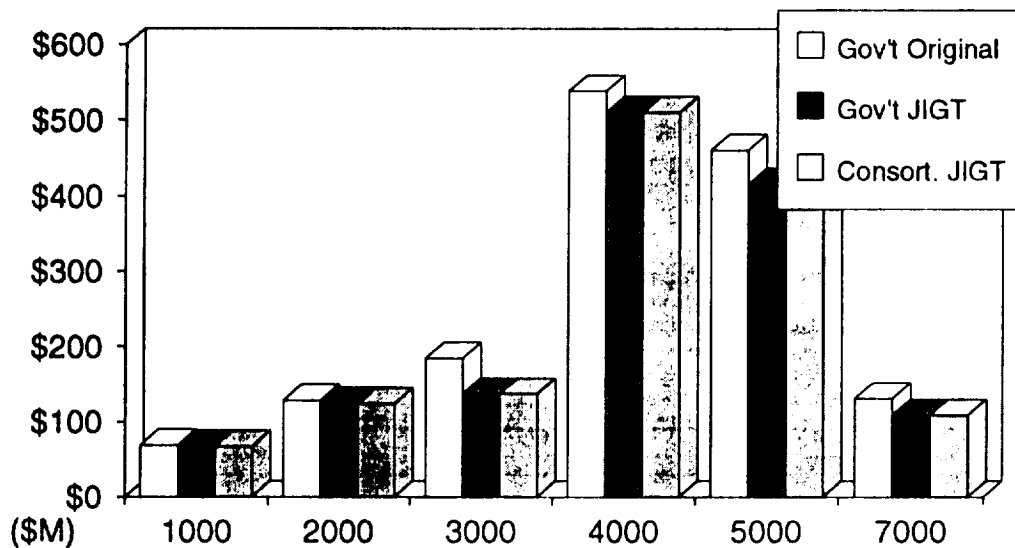
WBS	Description	Gov't (8/3/93)	Gov't JIGT (2/25/94)	Consortium JIGT (2/25/94)
1000	Site & Infrastructure	\$59,678	\$58,270	\$58,270
2000	Buildings	\$103,058	\$103,074	\$103,074
3000	Aux. Process Sys.	\$148,947	\$114,408	\$114,408
4000	LSWT	\$408,948	\$386,622	\$386,622
5000	TSWT	\$352,514	\$320,997	\$320,997
7000	Operations	\$106,479	\$89,056	\$89,056
8000	Mgmt.& Support	\$198,671	\$158,120	\$135,370
	<b>Engineering Est.</b>	<b>\$1,378,295</b>	<b>\$1,230,547</b>	<b>\$1,207,797</b>
	Risk	\$333,689	\$294,394	\$294,394
	<b>Sub-Total</b>	<b>\$1,711,984</b>	<b>\$1,524,941</b>	<b>\$1,502,191</b>
	Profit	\$171,198	\$152,494	\$0
	Bond	\$18,832	\$16,774	\$12,018
	Escalation	\$513,544	\$461,298	\$347,140
	Contingency	\$241,556	\$215,551	\$372,270
	Const. Mgmt (6%)	\$159,427	\$142,263	\$134,017
	Engr. Support (2%)	\$53,142	\$47,421	\$44,672
	<b>Total Construction Budget</b>	<b>\$2,869,683</b>	<b>\$2,560,743</b>	<b>\$2,412,308</b>
	PER	\$46,000	\$46,000	\$0
	Government PM	\$151,005	\$136,356	\$28,645
	Studies	\$38,523	\$11,460	\$8,660
	Design	\$118,181	\$100,800	\$100,800
	<b>PROGRAM TOTAL</b>	<b>\$3,223,393</b>	<b>\$2,855,359</b>	<b>\$2,550,412</b>

The comparisons for the Concept D - Option 5 JIGT cost estimates are provided in Figure 4.6. The Government Original cost estimate is the FSO cost estimate developed in September 1993. The Government JIGT cost estimate is the original FSO Concept D - Option 5 cost estimate upgraded to reflect the discoveries and changes made as discussed previously. The Consortium JIGT cost estimate is the Government JIGT cost estimate with the Consortium adders, management, and schedule philosophy incorporated.



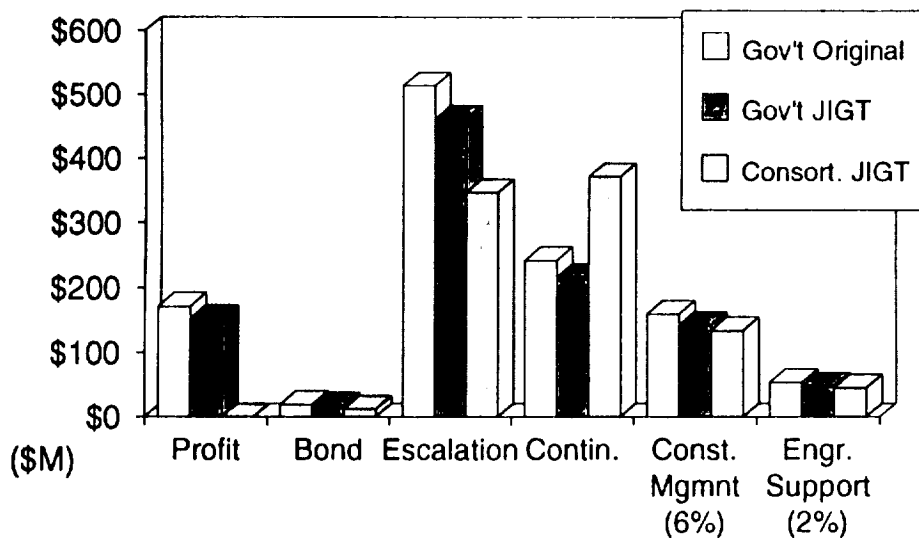
**Figure 4.6: Comparison of Categories for Concept D-5**

Changes are evident in all categories. The differences in the Technical category are the changes discussed in Section 4.2.1. The differences in the Management/Design and Adders categories are a mixture of new insight and philosophy changes. A detailed comparison of the changes in the Technical and Adders category are provided in Figures 4.7 and 4.8 respectively.



**Figure 4.7: Comparison of WBS Technical Categories for Concept D-5**

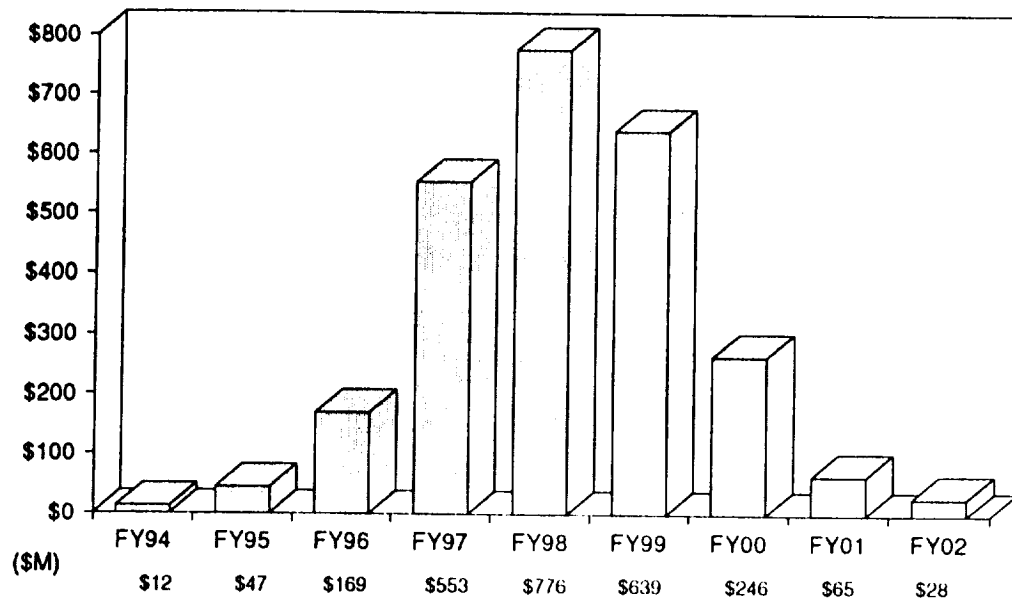
The changes from the Government Original to the Government JIGT cost are the improved understanding discussed in detail in the previous sections. Note there are no differences between the Government JIGT and the Consortium JIGT costs, because the base component cost is transparent to the procurement strategy employed. Other costs such as escalation, bond, etc. will be affected by the procurement strategy. The impact on the cost associated with the changes in the adders is provided in Figure 4.8.



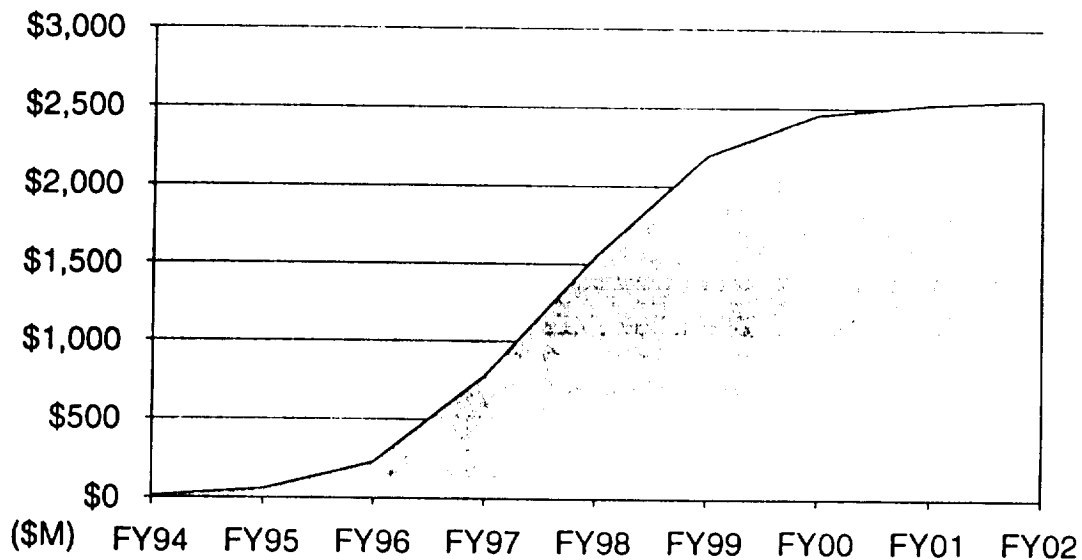
**Figure 4.8 Comparison of Adder Categories for Concept D-5**

The apparent differences between the Government Original and the Government JIGT costs reflect the use of percentages of the base technical cost. Therefore, if the base cost is reduced, the adder cost is also reduced. The largest areas of change that occurred to achieve the Consortium JIGT costs are in changing the Profit to zero and increasing the Contingency to 20%. The profit is normally viewed as the Contractor's contingency and the Contingency is the Program Office contingency. However, since the Industry Joint Venture is intended to be a "not for profit" entity, there needs to be a way to bank the risk mitigation funds (contingency). Therefore, the Contingency category was increased to 20%; 10% is associated with the NWTC performance risk and the other 10% is for unknown unknowns. The other category that exhibited a significant change was the escalation. The midpoint of construction was moved to one year earlier in the calendar.

If the Consortium cost estimate is now combined with the program schedule discussed in Section 3.0, the proposed spending profile can be determined. Figures 4.9 and 4.10 provide the spending profile for the Consortium approach to Concept D - Option 5. This spending profile is based upon a uniform expenditure of funds over the duration for the selected activities. Cost was assigned to each of the pertinent nodes in the schedule and then spread over the planned duration. If the duration changes, then this profile would change. This curve then can be used to determine the level of annual funding that would be required to ensure the Consortium maintains a net positive cash flow. The cumulative profile is provided in Figure 4.10.



**Figure 4.9: Concept D-5 Spending Profile for Consortium Procurement**



**Figure 4.10: Concept D-5 Cumulative Spending Profile for Consortium**

### 4.3 Cost Estimating Accuracy

The accuracy of a cost estimate is driven by a number of factors. These factors influence the overall program cost in a variety of ways (e. g., risk may be increased, overall program duration may be modified, or the overall program cost may grow). Table 3 lists a number of elements that affect the program cost. There is sufficient funds within the NWTC cost estimate to cover those elements listed below that exist within the current NWTC cost estimate. However, it is imperative that these

elements be considered in a timely manner so that adjustments can be made as required. The table is divided into two elements, Reason for Deviation and Method of Correction. Note there is not a specific one to one correspondence between each sub-element.

**Table 3: Factors Influencing the Accuracy of a Cost Estimate**

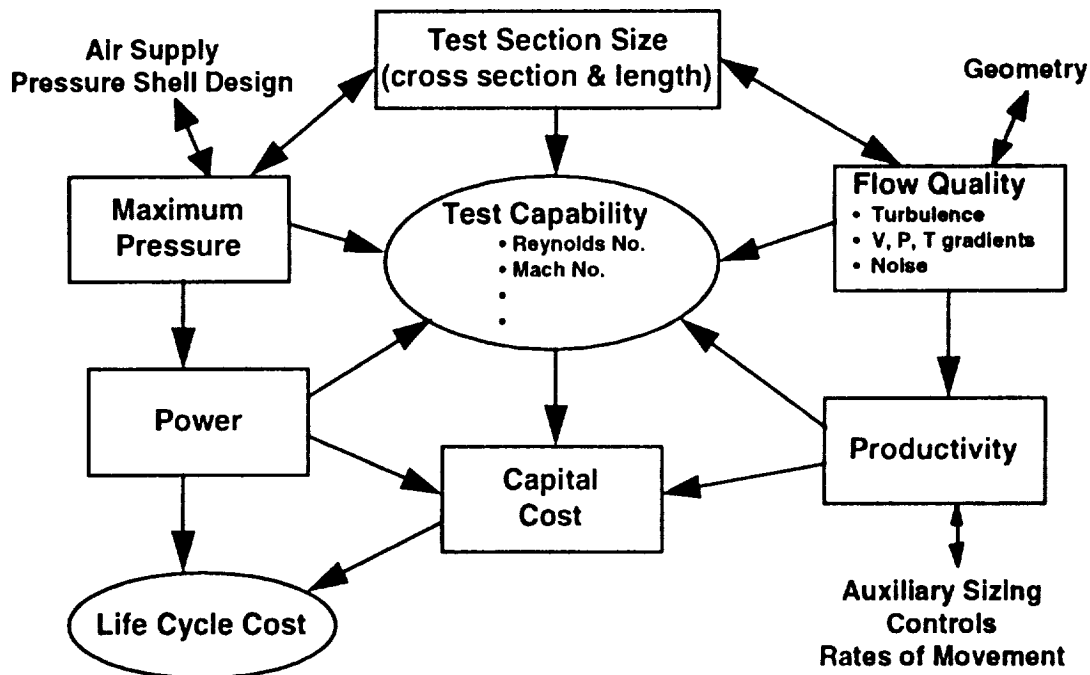
<b>Reason for Deviation</b>	<b>Method of Correction</b>
<b><i>Deviation of actual project from project at time of estimate</i></b>	
Requirements Site Acquisition Plan Schedule Funding	Review requirements and develop consensus Develop project cost for generic and high/low construction index Follow consortium model for schedule and acquisition plan Examine funding scenarios and use worse case Estimate risk and contingency for uncertainties
<b><i>Variations in effectiveness of Project Management performance</i></b>	
Level of autonomy Level of reviews - Management - Technical Staff quality and experience Organizational structure Organizational interfaces - Operational - Acquisition - Legal Control of cost and schedule Control of requirements and design Labor productivity Safety Value Engineering	Emphasize need for strong Industry and Government staffing commitments Adequate funds for studies, design, and Project Management Professional construction management Planning phase prior to Preliminary Design Phase
<b><i>Changes in economic conditions</i></b>	
Movement in rates and prices Availability of capital Level of competition Regulatory standards - OSHA - Environmental Labor - Availability - Conditions	Include escalation as a percentage of construction costs Develop work packages to maximize competition Define funding profile Include contingency for uncertainties

<b><i>Changes in environmental conditions</i></b>	
EAVEIS <ul style="list-style-type: none"> <li>- Cost</li> <li>- Schedule</li> </ul> Weather - including hurricanes Earthquakes	Perform survey of response times for typical EIS Use high/low construction index to reflect influence of weather
<b><i>Accidental events during construction and checkout</i></b>	
Fire Construction accidents Floods Explosions Earthquakes Wind damage	Insurance by contractors or consortium Construction bonds
<b><i>Imperfections in estimating methods</i></b>	
Inadequate concepts Incomplete design Lack of understanding requirements Lack of interface definition Inaccurate forecast of conditions in procurement and construction Technical complexity	Refine concepts and engineering requirements Include risk and contingency Define studies
<b><i>Estimating errors and oversights</i></b>	
Calculation errors Data input errors Failure to include all labor, material, etc. Failure to consider all information available to project Deliberate underestimate Interfaces Sloppy practices	Independent reviews Parallel estimates Checklists Include risk

## 5. Urgent Studies

### 5.1 Identification - Report of the Studies Working Group

The Joint Industry Government Team Studies Working Group task was to review the proposed studies (Appendix 5), validate the need, determine if a separate activity is required, and identify areas that needed immediate attention to reduce the uncertainty of the concept solution to satisfy the National Consensus Requirements. It was assumed that NWTC procurement will be managed by an Industry Joint Venture arrangement responding to government established, National Consensus Requirements.



**Figure 5.1: System Optimization Process**

The tunnel circuit arrangements for Concept D - Option 5 were leveraged from Concept A without regard to optimizing the circuit components from a systems viewpoint. Figure 5.1 depicts the system optimization process and indicates some of the complex interactions between the elements. For example, selection of the geometric tunnel contraction ratio effects the honeycomb/screens, nozzle, test section, isolation valves, diffuser, compressor, and heat exchanger designs and the circuit cross section and length; all of which influence flow quality, test capability, productivity, auxiliary systems, capital cost, and life cycle cost. Optimization of one component may lead to undesirable, sub-optimal designs for others. Therefore, the NWTC must be considered as a system in order to achieve the most cost effective solution. Furthermore, figures of merit for making trade decisions have not been established. For example, minimum cost solutions will depend on whether capital, operating, or life cycle costs are used as the figure of merit. Also, it was assumed

that all requirements specified by the Aero-Facilities Task Group (AFTG) would be met regardless of cost. It may be possible to achieve more cost effective solutions by slightly relaxing requirements in some areas. Guidelines, the decision process, and the approval authority should be established for making trade decisions. Once figures of merit and requirement tolerances are established, trade studies and design optimization decisions can be made on a consistent basis. The figures of merit should be established by a Joint Government Industry Team (a precursor to the formal Consortium).

## **5.2 Urgent Studies**

Three areas of urgent concern were identified as requiring resolution prior to the preliminary design activity. First is an optimization of the aerodynamic lines, internal component arrangements, and acoustical treatment for each wind tunnel to achieve the capability and flow quality requirements. This optimized configuration would become the baseline configuration for the subsequent design activities. Second, and closely coupled with the tunnel circuit optimization, is the determination of the baseline concepts for the test carts, test sections, model supports, isolation valves, the choke and reentry region, and the external balance load path and anchor point. These items primarily effect productivity and power, but also will have an impact on the baseline circuit definition. The third area of concern is the ability to achieve the required data quality in the LSWT with a Mach number of 0.6 in the open jet mode and with models large enough to achieve the required Reynolds number capability in either tunnel. An independent task is required to address each of these state-of-the-art stretching issues. The open jet investigation will survey available information and conduct analyses to recommend a baseline configuration. The large model investigation will analyze the potential wall interference in each tunnel to determine if the required data quality and Reynolds number can be achieved simultaneously.

Other concerns requiring early resolution by the Consortium are the criteria by which the complex will be designed (e.g., ASME codes, IEEE codes, safety standards, software standards, uncertainty standards, measurement standards, drawing standards, etc.), the system engineering plan to be followed by the Consortium and its contractors and designers, the design tools (e.g., CAD/CAM version, etc.) to be used by the designers, and the knowledge management system to be used by the Consortium to manage the project as well as by the subsequent operator during the life of the complex.

## **5.3 Government Studies**

JIGT felt there are two efforts best done by Government agencies in coordination with industry: (1) development of ventilated test section wall configurations and data correction procedures to bring wall interference increments to acceptable values, and (2) determine the most effective tunnel wall boundary layer treatment that will allow acceptable data to be obtained with floor mounted half models.

#### **5.4 Design Verification Studies**

The final category of recommended studies contains experimental and analytical tasks that are required to verify that the aerodynamic designs of critical items will meet the performance and flow quality requirements. The design verification tests should be conducted by agencies who are not responsible for the designs. Further, the verification tests should be completed in time to allow design modifications prior to manufacture if they become necessary to meet performance requirements.

#### **5.5 Design Studies**

The remainder of the studies were incorporated into the design activity. A list of the engineering studies whose need was verified is provided in Appendix 5.

## 6. Summary

A team representing the Government (NASA and DoD - AEDC) and the Aerospace Industry was convened at Langley Research Center in February of 1994 to assess methods of reducing the overall program cost and schedule for the National Wind Tunnel Complex. This team used the National Consensus Requirements (Concept D - Option 5) and the proposed configuration of this concept for these activities. The team was divided into working groups that focused on technical and the related cost issues, schedule development and assessment issues, and program management and procurement issues.

The program management and procurement team developed models for the Consortium, identified numerous "Best Business Practices" that should be adopted, and determined the necessary cost adders to be used. Key features of the Consortium are: (1) the Industry Joint Venture will be a legal "not for profit" business entity, (2) the Industry Joint Venture will assume responsibility for settlement of contract related disputes, protests, and lawsuits, (3) it will guarantee that NWTC performance meets requirements at initial operation and for a warrantee period of 2 years, (4) The NWTC constraints, interfaces, and requirements will be clearly defined and will not be subject to unilateral modification by the Industry Joint Venture or the Government during project execution, and (5) Capital budget will be fixed in both a yearly expenditure profile and total cost. Numerous issues associated with the formation of the Consortium, the relationship between the Industry Joint Venture and the Government, roles and responsibilities of all involved, funding, and NWTC operations have been identified. It is the responsibility of the NWTC Program Office to provide an assessment of these issues.

The technical team provided a review of the FSO Concept A cost estimate as compared with the Boeing Wind Tunnel program cost. Numerous differences were uncovered and discussed. These discussions led to discoveries that required revisions and changes to both cost estimates. The result was that the FSO cost estimate was reduced from \$2.32 Billion to \$2.12 Billion and the Boeing cost estimate was increased from \$1.03 Billion to \$1.24 Billion. Using the Consortium approach, the FSO cost estimate was further reduced to \$1.89 Billion. See Table 1 for the complete results. Upon conclusion of the Concept A review, a review of Concept D - Option 5 was conducted. The results were similar with the FSO cost estimate being reduced from \$3.22 Billion to \$2.86 Billion for a Government Procurement and \$2.55 Billion for the Consortium Procurement.

The schedule team was tasked with developing the schedule assuming a Consortium and "Best Business Practices". The technical team provided assistance in determining the Predecessor and Successor logic and the prospective durations of activities. The schedule assumed a program start date of April 1, 1994. A number of assumptions were made for the development of the schedule. Key assumptions were: (1) the use of concurrent engineering and

parallel design and construction activities, (2) Industry procurement practices (all procurements are 4 months or less), (3) Formation of the Consortium is part of the schedule, (4) Site selection occurs within 8 months from project start, and (5) funding is available when it is needed. The net result of the schedule activity is a total program duration of 8 years. The TSWT would be ready for the first customer by March 2002, or 7 years and 11 months from the project start.

The JIGT has provided an assessment of the impact on the program cost and duration of the National Wind Tunnel Complex - Concept D - Option 5 if commercial procurement practices and a Consortium procurement approach for the program are adopted. In addition, numerous "Best Business Practices" have been identified to be adopted to ensure the success of the program. Issues associated with the Consortium have been raised. However, resolution of these issues or recommendations on action plans have not been developed. The results of the recent JIGT activities was a reduction of \$365M was realized through a thorough scrubbing of the base line cost estimate assuming a standard Government Procurement approach. An additional \$305M reduction and approximately a 1.5 year reduction in the program schedule could be realized by using the Consortium procurement approach.

**National Wind Tunnel Complex**  
**Joint Industry Government Team**

**Appendix 1**

**Concept A Cost Estimate**  
**Data Sheets**

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National Wind Tunnel Complex									
FSO Concept A (8/3/93)									
Draft Facility Cost Estimate									
(Dollars in Thousand)									
Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
1	1000	Site And Infrastructure	\$56,354	15%	\$54,977	\$3,830	\$68,807		\$68,807
	1100	Site Preparation						\$72	
	1110	Investigation (Design Process Only)	\$0	0%	\$0	\$0	\$0		
	1120	Clearing And Grubbing	\$46	50%	\$69	5%	\$72		
	1130	Demolition	\$0	0%	\$0	\$0	\$0		
	1140	Dewatering	\$0	0%	\$0	\$0	\$0		
	1200	Site Improvements						\$5,050	
	1210	Earthwork	\$1,583	15%	\$1,820	3%	\$1,875		
	1220	Drainage	\$361	25%	\$451	3%	\$465		
	1230	Roads & Paving	\$1,405	20%	\$1,686	6%	\$1,787		
	1240	Rail System	\$0	0%	\$0	0%	\$0		
	1250	Waterway Improvements	\$376	15%	\$432	6%	\$458		
	1260	Landscaping	\$45	10%	\$50	6%	\$52		
	1270	Fencing And Gates	\$338	15%	\$389	6%	\$412		
2	1300	Utility Supply and Distribution Systems						\$3,783	
	1310	Central Heat Pump System	\$0	0%	\$0	0%	\$0		
	1320	Central HVAC Chiller System	\$0	0%	\$0	0%	\$0		
	1330	Water Supply And Treatment System	\$767	15%	\$882	6%	\$935		
	1340	Sanitary Wastewater Collection And Treatment Sys	\$256	15%	\$294	6%	\$312		
	1350	Natural Gas Distribution System	\$675	15%	\$776	6%	\$823		
	1360	Yard Fire Protection System	\$937	15%	\$1,078	6%	\$1,142		
	1370	Compressed Air System	\$468	15%	\$538	6%	\$570		
	1380	Steam System	\$0	0%	\$0	0%	\$0		
2	1400	Yard Electrical System						\$58,634	
	1410	Electrical Equipment	\$48,100	15%	\$55,315	6%	\$58,634		
	1420	Electrical Material (Included In 4110)	\$0	0%	\$0	0%	\$0		
2	1500	Other Electrical Systems						\$1,268	
	1510	Lighting Systems	\$71	20%	\$85	6%	\$90		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	1520	Communication Systems	\$209	20%	\$251	8%	\$266		
	1530	Security Systems	\$369	20%	\$443	8%	\$469		
	1540	Grounding	\$29	20%	\$35	8%	\$37		
	1550	Cathodic Protection	\$101	20%	\$121	8%	\$128		
	1560	Lightning Protection	\$101	20%	\$121	8%	\$128		
	1570	Freeze Protection	\$57	20%	\$68	8%	\$73		
	1580	Environmental Monitoring	\$24	20%	\$29	8%	\$31		
	1590	DC Power for Instrumentation	\$36	20%	\$43	8%	\$46		
1	2000	Buildings	\$79,297	24%	\$98,087	\$5,785	\$103,872		\$103,872
1	2100	Test Preparations/Control Building						\$42,322	
	2110	LSWT/TSWT...Prep/Control	\$31,941	25%	\$39,926	8%	\$42,322		
1	2200	Wind Tunnel Drive Buildings						\$10,079	
	2210	LSWT Drive Building	\$1,985	15%	\$2,283	8%	\$2,465		
	2220	TSWT Drive Building	\$6,130	15%	\$7,050	8%	\$7,613		
1	2300	Support Buildings						\$38,434	
	2310	Model Shop And Warehouse	\$19,556	25%	\$24,445	8%	\$25,912		
	2320	Support Shop Building(Included in 2110)	\$0	0%	\$0	0%	\$0		
	2330	Engineering Office	\$2,051	20%	\$2,461	8%	\$2,658		
1	2340	Guard House	\$205	10%	\$226	8%	\$239		
	2350	Outfitting	\$8,021	20%	\$9,625	0%	\$9,625		
1	2400	Utility Buildings						\$13,037	
	2410	WT Press/Vac Building	\$3,179	25%	\$3,974	8%	\$4,292		
	2420	Not Used	\$0	0%	\$0	0%	\$0		
	2430	Heat Pump System Equipment Building	\$0	0%	\$0	0%	\$0		
	2440	HVAC Chiller Building	\$0	0%	\$0	0%	\$0		
	2450	Utility Tunnels	\$6,021	30%	\$7,827	8%	\$8,453		
	2460	Other Minor Buildings	\$208	30%	\$270	8%	\$292		
	2470	Motor Pool Vehicles (Transferred to 2350)	\$0	0%	\$0	0%	\$0		
3	3000	Auxiliary Process Systems	\$108,642	23%	\$133,625	\$6,795	\$140,420		\$140,420
3	3100	Test Model And Cart Transport						\$2,912	
	3110	LSWT/TSWT Shuttle Carts	\$2,000	30%	\$2,600	12%	\$2,912		
	3120	TSWT Shuttle Carts (Transferred to 3110)	\$0	0%	\$0	0%	\$0		
3	3200	Wind Tunnel Pressurization/Vacuum System						\$87,229	
	3210	Compressors, Drivers, Pumps, Etc.	\$31,700	30%	\$41,210	3%	\$42,446		
	3220	Heaters And Coolers	\$615	20%	\$738	5%	\$775		
	3230	Drier System	\$6,485	20%	\$7,782	1%	\$7,860		
	3240	Filters	\$1,900	20%	\$2,280	1%	\$2,303		
	3250	Distribution Piping	\$10,930	20%	\$13,116	10%	\$14,428		
	3260	Storage Tanks	\$12,361	15%	\$14,215	6%	\$15,068		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	3270	Muffler Towers	\$1,455	15%	\$1,673	0%	\$1,774		
	3280	Vacuum System	\$2,209	10%	\$2,430	0%	\$2,576		
3	3400	Cooling System						\$16,385	
	3410	Cooling Towers	\$7,226	20%	\$8,671	1%	\$8,758		
	3420	Cw Circ Pumps & Motors	\$2,189	20%	\$2,627	1%	\$2,653		
	3430	Miscellaneous Equipment	\$138	20%	\$166	8%	\$179		
	3440	Distribution System Piping	\$3,700	20%	\$4,440	8%	\$4,795		
6	3500	Not Used							
3	3600	Miscellaneous Support Systems						\$20,773	
	3610	Tunnel Clearing System	\$3,600	30%	\$4,680	10%	\$5,148		
	3620	Air System(4500psi)	\$11,837	20%	\$14,204	10%	\$15,625		
	3630	Compressor Blade Handling System(Transferred to Scavenging And Fire Suppression System)	\$0	0%	\$0	0%	\$0		
3	3700	Scavenging And Fire Suppression System						\$0	
	3710	Combustible Gas Scavenging System (Not in Concept)	\$0	0%	\$0	0%	\$0		
	3720	Tunnel Fire Suppression System (Not in Concept A)	\$0	0%	\$0	0%	\$0		
2	3800	Aux. Electr Control Systems And Data Acquisition						\$4,262	
	3810	Electrical Equipment	\$3,496	15%	\$4,020	0%	\$4,262		
	3820	Electrical Bulks(Included in 3810)	\$0	0%	\$0	0%	\$0		
	3830	Control System (Transferred to 7710)	\$0	0%	\$0	0%	\$0		
	3840	Data Acquisition And Processing Systems (Transfer to Auxiliary Test And Validation)	\$0	0%	\$0	0%	\$0		
3	3900	Auxiliary Test And Validation						\$4,540	
	3910	Test And Validation	\$2,497	20%	\$2,996	1%	\$3,026		
	3920	Calibration	\$1,249	20%	\$1,498	1%	\$1,513		
	3A00	Productivity Provisions						\$4,320	
	3A10	Productivity Provisions	\$3,055	40%	\$4,277	1%	\$4,320		
4	4000	Low Speed Wind Tunnel	\$227,286	30%	\$296,232	\$23,979	\$320,211		\$320,211
4	4100	LSWT Enclosure						\$27,439	
	4110	Foundation	\$8,236	20%	\$9,883	8%	\$10,674		
	4120	Enclosure	\$12,016	20%	\$14,419	8%	\$15,573		
	4130	Acoustic Insulation	\$317	20%	\$380	8%	\$403		
	4140	Electrical Services	\$326	15%	\$375	8%	\$397		
	4150	Mechanical Services	\$321	15%	\$369	8%	\$391		
4	4200	LSWT Pressure Shell						\$111,829	
	4210	LSWT Support Foundation(Included in 4110)	\$0	0%	\$0	0%	\$0		
	4220	LSWT Support Structure	\$9,013	25%	\$11,266	4%	\$11,717		
	4230	LSWT Pressure Shell	\$77,009	25%	\$96,261	4%	\$100,112		
4	4300	LSWT Pressure Isolation System						\$8,777	
	4310	LSWT Isolation Valves	\$4,500	60%	\$7,200	20%	\$8,640		
	4320	LSWT Personnel Access (Not In Concept A)	\$0	0%	\$0	0%	\$0		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor	Const. Cost	Design Estimate	Item Total	Subtotal	Total
				%		%			
	4330	Hydraulic Power Unit	\$100	30%	\$130	9%	\$137		
	4340	Exhaust Silencer (Transferred to 3270)	\$0	0%	\$0	0%	\$0		
4	4400	LSWT Flow Internals						\$35,368	
	4410	Turning Vanes	\$4,400	30%	\$5,720	15%	\$6,578		
	4420	Honeycomb	\$2,040	30%	\$2,652	15%	\$3,050		
	4430	Screens	\$1,900	30%	\$2,470	15%	\$2,841		
	4440	Internal Heat Exchanger	\$6,500	20%	\$7,800	9%	\$8,190		
	4450	Settling Chamber Liner	\$8,619	30%	\$11,205	15%	\$12,885		
	4460	Plenum Evacuation System (Not in Concept A)	\$0	0%	\$0	0%	\$0		
	4470	Gas Manifolding(Not in Concept A)	\$0	0%	\$0	0%	\$0		
	4480	High Speed Diffuser	\$1,220	30%	\$1,586	15%	\$1,824		
	4490	Acoustic Treatment for nacelles (Not in Concept A)	\$0	0%	\$0	0%	\$0		
	44A0	Compressor FOD Protection (Not Used)	\$0	0%	\$0	0%	\$0		
	44B0	Acoustic Baffles (Not in Concept A)	\$0	0%	\$0	0%	\$0		
	44C0	Tunnel Cleaning System (Transferred to 3610)	\$0	0%	\$0	0%	\$0		
4	4500	Test Plenum						\$49,960	
	4510	Subsonic Nozzle (Transferred to 4450)	\$0	0%	\$0	0%	\$0		
	4520	Flutter Test Section (Not in Concept A)	\$0	0%	\$0	0%	\$0		
	4530	Open Jet Test Section	\$3,605	60%	\$5,768	20%	\$6,922		
	4540	Moveable Plenum	\$6,506	40%	\$9,108	15%	\$10,475		
	4550	Not used	\$0	0%	\$0	0%	\$0		
	4560	Observation System	\$350	40%	\$490	15%	\$564		
	4570	Test Section Carts	\$16,000	60%	\$25,600	25%	\$32,000		
	4580	Preparation Hall Shuttle Cart (Transferred to 3110)	\$0	0%	\$0	0%	\$0		
	4590	Anechoic Chamber (Not in Concept A)	\$0	0%	\$0	0%	\$0		
4	4600	Test Support Equipment						\$11,700	
	4610	Vertical Strut Assembly (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
	4620	Floor Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
	4630	Half Model Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
	4640	Moving Ground Plane (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
	4650	Elevated Ground Plane	\$1,200	50%	\$1,800	15%	\$2,070		
	4660	Inverted Ground Plane	\$1,200	50%	\$1,800	15%	\$2,070		
	4670	Slit (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
	4680	External Balance	\$4,500	40%	\$6,300	20%	\$7,560		
6	4700	Compressor and Drive System						\$41,660	
	4710	Rotor Hub/Blades	\$7,800	30%	\$10,140	3%	\$10,444		
	4720	Shaft/Bearings/Clutch	\$2,360	25%	\$2,950	2%	\$3,009		
	4730	Nacelles/Fairings and Supports	\$1,760	30%	\$2,288	9%	\$2,402		
	4740	Gearbox	\$0	0%	\$0	0%	\$0		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	4750	Lubrication and Cooling System	\$160	20%	\$192	5%	\$202		
	4760	Motor	\$3,000	20%	\$3,600	1%	\$3,636		
	4770	Motor Drive Controls	\$9,000	20%	\$10,800	2%	\$11,016		
	4780	Compressor Pressure Shell/Stators/GV/OGV	\$7,020	50%	\$10,530	4%	\$10,951		
6	4800	Electrical, Controls System and Data Acquisition						\$0	
	4810	Electrical Equipment	\$0	0%	\$0	0%	\$0		
	4820	Electrical Materials	\$0	0%	\$0	0%	\$0		
	4830	Control and Instrumentation (Transferred to 7720)							
	4840	Data Acquisition and Processing Systems (Transferred to 7220)							
4	4900	Test & Validation							
	4910	Test and Validation	\$13,154	20%	\$15,785	1%	\$15,943	\$22,320	
	4920	Calibration	\$5,262	20%	\$6,314	1%	\$6,377		
	4A00	Productivity Provisions						\$11,160	
	4A10	Productivity Provisions	\$7,893	40%	\$11,050	1%	\$11,160		
5	5000	Transonic Wind Tunnel (TSWT)	\$262,116	28%	\$335,358	\$19,114	\$354,472		\$354,472
5	5100	TSWT Acoustic Enclosure						\$23,649	
	5110	Foundation	\$6,719	20%	\$8,063	8%	\$8,708		
	5120	Enclosure	\$10,675	20%	\$12,810	8%	\$13,835		
	5130	Acoustic Insulation	\$317	20%	\$380	6%	\$403		
	5140	Electrical Services	\$291	15%	\$335	6%	\$355		
	5150	Mechanical Services	\$286	15%	\$329	6%	\$349		
5	5200	Pressure Vessels						\$54,541	
	5210	Foundations (Included in 5110)	\$0	0%	\$0	0%	\$0		
	5220	Shell Support System	\$4,515	25%	\$5,644	5%	\$5,926		
	5230	TSWT Pressure Shell	\$37,040	25%	\$46,300	5%	\$48,615		
5	5300	Pressure Isolation System						\$8,442	
	5310	TSWT Isolation Valves	\$3,570	100%	\$7,140	15%	\$8,211		
	5320	TSWT Personnel Access	\$0	0%	\$0	0%	\$0		
	5330	Hydraulic Power Unit	\$150	40%	\$210	10%	\$231		
5	5400	TSWT Flow Internals						\$66,327	
	5410	Turning Vanes	\$4,275	20%	\$5,130	10%	\$5,643		
	5420	Honeycomb	\$1,019	30%	\$1,325	10%	\$1,457		
	5430	Screens	\$1,051	30%	\$1,366	10%	\$1,503		
	5440	Internal Heat Exchanger	\$7,105	30%	\$9,237	10%	\$10,160		
	5450	Settling Chamber Liner	\$2,040	40%	\$2,856	10%	\$3,142		
	5460	Plenum Evacuation System	\$23,240	20%	\$27,888	5%	\$29,282		
	5470	Acoustic Baffles	\$600	20%	\$720	15%	\$828		
	5480	Contouring Nozzle	\$2,500	30%	\$3,250	15%	\$3,738		
	5490	Compressor FOD Protection	\$3,400	20%	\$4,080	15%	\$4,692		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor	Const. Cost	Design Estimate	Item Total	Subtotal	Total
				%		%			
	54A0	Choke System	\$3,100	30%	\$4,030	20%	\$4,836		
	54B0	High Speed Diffuser Liner	\$650	40%	\$910	15%	\$1,047		
	54C0	Tunnel Cleaning System (Not Incl.)	\$0	0%	\$0	0%	\$0		
5	5500	TSWT Test Plenum						\$36,056	
	5510	Test Section	\$17,560	40%	\$24,584	12%	\$27,534		
	5520	Moveable Plenum	\$5,500	30%	\$7,150	15%	\$8,223		
	5530	Observation System	\$200	30%	\$260	15%	\$299		
	5540	Preparation Hall Shuttle Cart	\$0	0%	\$0	0%	\$0		
5	5600	TSWT Test Support Equipment						\$6,292	
	5610	Model Support (Incl. in 5510)	\$0	0%	\$0	0%	\$0		
	5620	Floor Mounts (Interface only)	\$0	0%	\$0	0%	\$0		
	5630	Half Model Mounts(Interface only)	\$0	0%	\$0	0%	\$0		
	5640	Stings and Booms(Incl. in 7440)	\$0	0%	\$0	0%	\$0		
	5650	External Balance	\$4,400	30%	\$5,720	10%	\$6,292		
	5660	Other Test Support Equipment(Incl. in 7740)	\$0	0%	\$0	0%	\$0		
6	5700	TSWT Compressor Drive System						\$123,758	
	5710	Rotor Hub/Blades	\$19,040	40%	\$26,656	3%	\$27,456		
	5720	Shaft/Bearings/Clutch	\$7,290	35%	\$9,842	2%	\$10,038		
	5730	Nacelles/Fairings and Supports	\$6,020	40%	\$8,428	5%	\$8,849		
	5740	Compressor Pressure Shell/Stators/IGV/OGV	\$9,180	40%	\$12,852	5%	\$13,495		
	5750	Lubrication & Cooling System	\$340	20%	\$408	5%	\$428		
	5760	Motors	\$13,000	20%	\$15,600	1%	\$15,756		
	5770	Motor Controls	\$39,000	20%	\$46,800	2%	\$47,736		
	5780	Gearbox Included With 3530	\$0	0%	\$0	0%	\$0		
6	5800	TSWT Elec. Control Systems and Data Acquisition						\$0	
	5810	Electrical Equipment	\$0	0%	\$0	0%	\$0		
	5820	Electrical Materials	\$0	0%	\$0	0%	\$0		
	5830	Control Systems (Transferred to 7730)							
	5840	Data Acquisition and Data Processing Systems (Transferred to 7230)							
5	5900	TSWT Test and Validation, Calibration						\$25,478	
	5910	Test and Validation	\$15,015	20%	\$18,018	1%	\$18,198		
	5920	Calibration	\$6,006	20%	\$7,207	1%	\$7,279		
	5A00	Productivity Items						\$9,929	
	5A00	Productivity Items	\$7,022	40%	\$9,831	1%	\$9,929		
7	7000	Operators (TSWT & TSWT)	\$82,279	23%	\$101,336	\$13,838	\$115,175		\$115,175
	7100	Calibration						\$32,913	
	7110	Auxiliary Process System Calibration	\$0	0%	\$0	0%	\$0		
	7120	Airflow Calibration Lab	\$2,628	50%	\$3,942	12%	\$4,415		
	7130	Balance Calibration Lab	\$10,500	20%	\$12,600	20%	\$15,120		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	7140	Structural Calibration Lab	\$187	10%	\$206	5%	\$216		
	7150	Instrument Calibration Lab	\$2,923	10%	\$3,215	10%	\$3,537		
	7160	Calibration Hardware - LSWT	\$304	20%	\$365	25%	\$456		
	7170	Calibration Hardware - TSWT	\$304	20%	\$365	25%	\$456		
	7180	Calibration Model	\$193	30%	\$251	25%	\$314		
	7190	External Balance Calibrator	\$5,000	40%	\$7,000	20%	\$8,400		
7	7200	Data Acquisition System						\$30,575	
	7210	Data Acquisition System - Aux. Systems (from 3840)	\$0	0%	\$0	0%	\$0		
	7220	Data Acquisition System - LSWT (from 4840)	\$12,250	20%	\$14,700	5%	\$15,435		
	7230	Data Acquisition System - TSWT (from 5840)	\$12,016	20%	\$14,419	5%	\$15,140		
7	7300	Wind Tunnel Balance						\$5,400	
	7310	Balance (Internal) LSWT	\$1,600	20%	\$1,920	25%	\$2,400		
	7320	Balance (Internal) TSWT	\$2,000	20%	\$2,400	25%	\$3,000		
7	7400	Models and Models Supports						\$4,632	
	7410	Model Handling Equipment (LSWT)(From 3120)	\$256	20%	\$307	8%	\$326		
	7420	Model Handling Equipment (TSWT)	\$256	20%	\$307	8%	\$326		
	7430	Slings and Struts (LSWT)	\$1,417	20%	\$1,700	16%	\$1,972		
	7440	Slings and Struts TSWT	\$1,443	20%	\$1,732	16%	\$2,009		
	7450	Acoustic Traverse Rake	\$0	0%	\$0	0%	\$0		
7	7500	Instrumentation						\$21,862	
	7510	Test (LSWT)	\$6,761	20%	\$8,113	12%	\$9,087		
	7520	Test (TSWT)	\$4,222	20%	\$5,066	12%	\$5,674		
	7530	Calibration (LSWT)	\$159	20%	\$191	18%	\$225		
	7540	Calibration (TSWT)	\$159	20%	\$191	18%	\$225		
	7550	Acoustics (LSWT)	\$0	0%	\$0	0%	\$0		
	7560	Acoustics (TSWT)	\$0	0%	\$0	0%	\$0		
	7570	Processes (LSWT)	\$1,851	20%	\$2,221	12%	\$2,488		
	7580	Process (TSWT)	\$1,668	20%	\$2,002	12%	\$2,242		
	7590	Hardware Integ. (LSWT)	\$305	15%	\$351	15%	\$403		
	75A0	Hardware Integ. (TSWT)	\$305	15%	\$351	15%	\$403		
	75B0	Aux. process Instr. LSWT & BWT	\$714	30%	\$928	20%	\$1,114		
7	7600	Operations Integration Analysis Plan						\$0	
	7610	Productivity (LSWT)	\$0	20%	\$0	0%	\$0		
	7620	Productivity (TSWT)	\$0	20%	\$0	0%	\$0		
	7630	Maintenance (LSWT)	\$0	20%	\$0	0%	\$0		
	7640	Maintenance (TSWT)	\$0	20%	\$0	0%	\$0		
	7650	Maintenance - Aux. Syst.	\$0	20%	\$0	0%	\$0		
	7660	Instr. Acc. Assessment LSWT & TSWT	\$0	25%	\$0	0%	\$0		
7	7700	Controls						\$19,792	



Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor	Const. Cost	Design Estimate	Item Total	Subtotal	Total
				%		%			
		PER							
		Government Project Management				2%	\$40,884	\$2,085,106	
		Studies				10%	\$102,961	\$2,188,068	
		Design(Including Design Management)					\$38,523	\$2,226,591	
		Real Estate					\$89,592	\$2,316,183	
		Other Burden Expense					\$0	\$2,316,183	
							\$0	\$2,316,183	
		Project Total					\$2,316,183		\$2,316,183



## National Wind Tunnel Complex

## FSO Concept

## Draft Facility Cost Estimate

(Dollars in Thousand)

### Concept A

### FSO Government Model

WBS No.	Item and Description	Engineering Estimate	Risk Factor	Const. Cost	Design Estimate	Item Total	Subtotal	Total
			%		%			
<b>1000 Site And Infrastructure</b>								
1100	Site Preparation	\$55,590	15%	\$64,099	\$3,802	\$67,901		\$67,901
1110	Investigation (Design Process Only)	\$0	0%	\$0	\$0	\$0	\$72	
1120	Clearing And Grubbing	\$46	50%	\$69	5%	\$72		
1130	Demolition	\$0	0%	\$0	\$0	\$0		
1140	Dewatering	\$0	0%	\$0	\$0	\$0		
1200	Site Improvements							
1210	Earthwork	\$848	15%	\$975	3%	\$1,004	\$4,144	
1220	Drainage	\$361	25%	\$451	3%	\$465		
1230	Roads & Paving	\$1,405	20%	\$1,686	6%	\$1,787		
1240	Rail System	\$0	0%	\$0	0%	\$0		
1250	Waterway Improvements	\$347	15%	\$399	6%	\$423		
1260	Landscaping	\$45	10%	\$50	6%	\$52		
1270	Fencing And Gates	\$338	15%	\$389	6%	\$412		
1300	Utility Supply and Distribution Systems							
1310	Central Heat Pump System	\$0	0%	\$0	0%	\$0	\$3,783	
1320	Central HVAC Chiller System	\$0	0%	\$0	0%	\$0		
1330	Water Supply And Treatment System	\$767	15%	\$882	6%	\$935		
1340	Sanitary Wastewater Collection And Treatment Sys	\$256	15%	\$294	6%	\$312		
1350	Natural Gas Distribution System	\$675	15%	\$776	6%	\$823		
1360	Yard Fire Protection System	\$937	15%	\$1,078	6%	\$1,142		
1370	Compressed Air System	\$468	15%	\$538	6%	\$570		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
1380	Steam System	\$0	0%	\$0	0%	\$0		
1400	Yard Electrical System						\$58,634	
1410	Electrical Equipment	\$48,100	15%	\$55,315	6%	\$58,634		
1420	Electrical Material (Included in 4110)	\$0	0%	\$0	0%	\$0	\$1,268	
1500	Other Electrical Systems							
1510	Lighting Systems	\$71	20%	\$85	6%	\$90		
1520	Communication Systems	\$209	20%	\$251	6%	\$266		
1530	Security Systems	\$369	20%	\$443	6%	\$469		
1540	Grounding	\$29	20%	\$35	6%	\$37		
1550	Cathodic Protection	\$101	20%	\$121	6%	\$128		
1560	Lightning Protection	\$101	20%	\$121	6%	\$128		
1570	Freeze Protection	\$57	20%	\$68	6%	\$73		
1580	Environmental Monitoring	\$24	20%	\$29	6%	\$31		
1590	DC Power for Instrumentation	\$36	20%	\$43	6%	\$46		
2000	Buildings	\$68,381	20%	\$82,326	\$4,755	\$87,081		\$87,081
2100	Test Preparations/Control Building						\$34,689	
2110	LSWT/...Prep/Control	\$27,271	20%	\$32,725	6%	\$34,689		
2120	TSWT/...Prep/Control							
2200	Wind Tunnel Drive Buildings						\$7,770	
2210	LSWT/TSWT Drive Building	\$1,438	15%	\$1,654	8%	\$1,786		
2220	Not Used	\$4,818	15%	\$5,541	8%	\$5,984		
2300	Support Buildings						\$31,491	
2310	Model Shop And Warehouse	\$14,343	20%	\$17,212	6%	\$18,244		
2320	Support Shop Building(Included in 2110)	\$0	0%	\$0	0%	\$0		
2330	Engineering Office	\$2,051	20%	\$2,461	8%	\$2,658		
2340	Guard House	\$205	10%	\$226	6%	\$239		
2350	Outfitting	\$8,625	20%	\$10,350	0%	\$10,350		
2400	Utility Buildings						\$13,131	
2410	WT Press/Vac Building	\$3,401	20%	\$4,081	8%	\$4,408		
2420	Not Used	\$0	0%	\$0	0%	\$0		
2430	Heat Pump System Equipment Building	\$0	0%	\$0	0%	\$0		
2440	HVAC Chiller Building	\$0	0%	\$0	0%	\$0		
2450	Utility Tunnels	\$6,021	30%	\$7,827	8%	\$8,453		
2460	Other Minor Buildings	\$208	20%	\$250	8%	\$270		
2470	Motor Pool Vehicles (Transferred to 2350)	\$0	0%	\$0	0%	\$0		
3000	Auxiliary Process Systems	\$103,530	18%	\$123,189	\$6,542	\$129,731		\$129,731
3100	Test Model And Cart Transport						\$2,912	
3110	LSWT Shuttle Cart	\$2,000	30%	\$2,600	12%	\$2,912		
3120	TSWT Shuttle Cart	\$0	0%	\$0	0%	\$0		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
3200	Wind Tunnel Pressurization/Vacuum System							
3210	Compressors, Dryers, Pumps, Etc.	\$31,281	20%	\$37,537	3%	\$38,663	\$82,994	
3220	Heaters And Coolers	\$615	20%	\$738	5%	\$775		
3230	Drier System	\$6,485	20%	\$7,782	1%	\$7,860		
3240	Filters	\$1,900	20%	\$2,280	1%	\$2,303		
3250	Distribution Piping	\$10,588	20%	\$12,706	10%	\$13,976		
3260	Storage Tanks	\$12,361	15%	\$14,215	6%	\$15,068		
3270	Muffler Towers	\$1,455	15%	\$1,673	6%	\$1,774		
3280	Vacuum System	\$2,209	10%	\$2,430	6%	\$2,576		
3400	Cooling System							
3410	Cooling Towers	\$4,835	20%	\$5,802	1%	\$5,860	\$12,997	
3420	Oil Circ Pumps & Motors	\$2,270	20%	\$2,724	1%	\$2,751		
3430	Miscellaneous Equipment	\$138	20%	\$166	8%	\$179		
3440	Distribution System Piping	\$3,246	20%	\$3,895	8%	\$4,207		
3500	Not Used							
3600	Miscellaneous Support Systems							
3610	Tunnel Cleaning System	\$3,600	30%	\$4,680	10%	\$5,148	\$20,773	
3620	Calibration System (High Pressure Air/Model Prop.)	\$11,837	20%	\$14,204	10%	\$15,625		
3630	Compressor Blade Handling System(Transferred to	\$0	0%	\$0	0%	\$0		
3700	Scavenging And Fire Suppression System							
3710	Combustible Gas Scavenging System (Not used)	\$0	0%	\$0	0%	\$0	\$0	
3720	Tunnel Fire Suppression System (Not used)	\$0	0%	\$0	0%	\$0		
3800	Aux. Electrl Control Systems And Data Acquisition							
3810	Electrical Equipment	\$3,496	15%	\$4,020	6%	\$4,262	\$4,262	
3820	Electrical Bulks(Included in 3810)	\$0	0%	\$0	0%	\$0		
3830	Control System (Transferred to 7710)	\$0	0%	\$0	0%	\$0		
3840	Data Acquisition And Processing Systems (Transfer	\$0	0%	\$0	0%	\$0		
3900	Auxiliary Test And Validation							
3910	Test And Validation	\$1,510	10%	\$1,661	1%	\$1,678	\$2,516	
3920	Calibration	\$755	10%	\$831	1%	\$839		
3A00	Productivity Provisions							
3A10	Productivity Provisions	\$2,949	10%	\$3,244	1%	\$3,277	\$3,277	
4000	Low Speed Wind Tunnel	\$212,537	30%	\$275,926	\$19,805	\$295,731	\$295,731	
4100	LSWT Enclosure							
4110	Foundation	\$8,661	20%	\$10,393	8%	\$11,225	\$22,680	
4120	Enclosure	\$7,919	20%	\$9,503	8%	\$10,263		
4130	Acoustic Insulation	\$317	20%	\$380	6%	\$403		
4140	Electrical Services	\$326	15%	\$375	6%	\$397		
4150	Mechanical Services	\$321	15%	\$369	6%	\$391		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
4200	LSWT Pressure Shell							
4210	LSWT Support Foundation( Incl. In 4110)	\$0	0%	\$0	0%	\$0		
4220	LSWT Support Structure	\$9,013	25%	\$11,266	4%	\$11,717		
4230	LSWT Pressure Shell	\$77,009	25%	\$96,261	4%	\$100,112		
4300	LSWT Pressure Isolation System						\$8,417	
4310	LSWT Isolation Valves	\$4,500	60%	\$7,200	15%	\$8,280		
4320	LSWT Personnel Access (Not used)	\$0	0%	\$0	0%	\$0		
4330	Hydraulic Power Unit	\$100	30%	\$130	5%	\$137		
4340	Exhaust Silencer (Transferred to 3270)	\$0	0%	\$0	0%	\$0		
4400	LSWT Flow Internals						\$35,517	
4410	Turning Vanes	\$4,400	30%	\$5,720	15%	\$6,578		
4420	Honeycomb	\$2,040	30%	\$2,652	15%	\$3,050		
4430	Screens	\$1,900	30%	\$2,470	15%	\$2,841		
4440	Internal Heat Exchanger	\$6,500	20%	\$7,800	5%	\$8,190		
4450	Settling Chamber Liner	\$8,619	30%	\$11,205	15%	\$12,885		
4460	Plenum Evacuation System (Not used)	\$0	0%	\$0	0%	\$0		
4470	Gas Manifolding(Not used)	\$0	0%	\$0	0%	\$0		
4480	High Speed Diffuser	\$1,220	30%	\$1,586	15%	\$1,824		
4490	Acoustic Treatment for nacelles	\$0	0%	\$0	0%	\$0		
44A0	Compressor FOD Protection	\$100	30%	\$130	15%	\$150		
44B0	Acoustic Baffles (Not used)	\$0	0%	\$0	0%	\$0		
44C0	Tunnel Cleaning System(Transferred to 3610)	\$0	0%	\$0	0%	\$0	\$41,758	
4500	Test Plenum							
4510	Subsonic Nozzle(Transferred to 4450)	\$0	0%	\$0	0%	\$0		
4520	Flutter Test Section (Not in Concept )	\$0	0%	\$0	0%	\$0		
4530	Open Jet Test Section	\$0	0%	\$0	0%	\$0		
4540	Moveable Plenum	\$6,506	40%	\$9,108	15%	\$10,475		
4550	Not used	\$0	0%	\$0	0%	\$0		
4560	Observation System	\$350	40%	\$490	15%	\$564		
4570	Test Section Carts	\$16,000	60%	\$25,600	20%	\$30,720		
4580	Preparation Hail Shuttle Cart	\$0	0%	\$0	0%	\$0		
4590	Anechoic Chamber	\$0	0%	\$0	0%	\$0	\$10,755	
4600	Test Support Equipment							
4610	Vertical Strut Assembly (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
4620	Floor Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4630	Half Model Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4640	Moving Ground Plane (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
4650	Elevated Ground Plane	\$1,200	50%	\$1,800	15%	\$2,070		
4660	Inverted Ground Plane	\$1,200	50%	\$1,800	15%	\$2,070		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
4670	Sting (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4680	External Balance	\$4,500	40%	\$6,300	5%	\$6,615		
4700	Compressor and Drive System						\$41,660	
4710	Rotor Hub/Blades	\$7,800	30%	\$10,140	3%	\$10,444		
4720	Shaft/Bearings/Clutch	\$2,360	25%	\$2,950	2%	\$3,009		
4730	Nacelles/Fairings and Supports	\$1,760	30%	\$2,288	5%	\$2,402		
4740	Gearbox	\$0	0%	\$0	0%	\$0		
4750	Lubrication and Cooling System	\$160	20%	\$192	5%	\$202		
4760	Motor	\$3,000	20%	\$3,600	1%	\$3,636		
4770	Motor Drive Controls	\$9,000	20%	\$10,800	2%	\$11,016		
4780	Compressor Pressure Shell/Stators/IGV/OGV	\$7,020	50%	\$10,530	4%	\$10,951		
4800	Electrical, Controls System and Data Acquisition						\$0	
4810	Electrical Equipment (Transferred to 1410)	\$0	0%	\$0	0%	\$0		
4820	Electrical Materials (Transferred to 1420)	\$0	0%	\$0	0%	\$0		
4830	Control and Instrumentation (Transferred to 7720)							
4840	Data Acquisition and Processing Systems (Transferred to 7720)							
4900	Test & Validation						\$12,382	
4910	Test and Validation	\$7,960	10%	\$8,756	1%	\$8,844		
4920	Calibration	\$3,185	10%	\$3,504	1%	\$3,539		
4A00	Productivity Provisions							
4A10	Productivity Provisions	\$7,591	40%	\$10,628	1%	\$10,734	\$10,734	
5000	Transonic Wind Tunnel (TSWT)	\$251,742	28%	\$322,063	\$18,482	\$340,545		\$340,545
5100	TSWT Enclosure						\$21,039	
5110	Foundation	\$8,051	20%	\$9,661	8%	\$10,434		
5120	Enclosure	\$7,333	20%	\$8,800	8%	\$9,504		
5130	Acoustic Insulation	\$284	20%	\$341	6%	\$361		
5140	Electrical Services	\$306	15%	\$352	6%	\$373		
5150	Mechanical Services	\$301	15%	\$346	6%	\$367		
5200	Pressure Vessels						\$54,541	
5210	Foundations	\$0	0%	\$0	0%	\$0		
5220	Shell Support System	\$4,515	25%	\$5,644	5%	\$5,926		
5230	TSWT Pressure Shell	\$37,040	25%	\$46,300	5%	\$48,615		
5300	Pressure Isolation System						\$8,442	
5310	TSWT Isolation Valves	\$3,570	100%	\$7,140	15%	\$8,211		
5320	TSWT Personnel Access	\$0	0%	\$0	0%	\$0		
5330	Hydraulic Power Unit	\$150	40%	\$210	10%	\$231		
5400	TSWT Flow Internals						\$66,327	
5410	Turning Vanes	\$4,275	20%	\$5,130	10%	\$5,643		
5420	Honeycomb	\$1,019	30%	\$1,325	10%	\$1,457		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
5430	Screens	\$1,051	30%	\$1,366	10%	\$1,503		
5440	Internal Heat Exchanger	\$7,105	30%	\$9,237	10%	\$10,160		
5450	Settling Chamber Liner	\$2,040	40%	\$2,856	10%	\$3,142		
5460	Plenum Evacuation System	\$23,240	20%	\$27,888	5%	\$29,282		
5470	Acoustic Baffles	\$600	20%	\$720	15%	\$828		
5480	Flexible Nozzle	\$2,500	30%	\$3,250	15%	\$3,738		
5490	Compressor FOD Protection	\$3,400	20%	\$4,080	15%	\$4,692		
54A0	Choke System	\$3,100	30%	\$4,030	20%	\$4,836		
54B0	High Speed Diffuser Liner	\$650	40%	\$910	15%	\$1,047		
54C0	Ejection System	\$0	0%	\$0	0%	\$0	\$36,056	
5500	TSWT Test Plenum							
5510	Test Section	\$17,560	40%	\$24,584	12%	\$27,534		
5520	Moveable Plenum	\$5,500	30%	\$7,150	15%	\$8,223		
5530	Observation System	\$200	30%	\$260	15%	\$299		
5540	Preparation Hall Shuttle Cart	\$0	0%	\$0	0%	\$0	\$6,406	
5600	TSWT Test Support Equipment							
5610	Model Support (Incl. In 5510)	\$0	0%	\$0	0%	\$0		
5620	Floor Mounts (Interface only)	\$0	0%	\$0	0%	\$0		
5630	Half Model Mounts(Interface only)	\$0	0%	\$0	0%	\$0		
5640	Stings and Booms(Incl. In 7440)	\$4,400	40%	\$6,160	4%	\$6,406		
5650	External Balance	\$0	0%	\$0	0%	\$0		
5660	Other Test Support Equipment(Incl. In 7740)	\$0	0%	\$0	0%	\$0	\$123,758	
5700	TSWT Compressor Drive System							
5710	Rotor Hub/Blades	\$19,040	40%	\$26,656	3%	\$27,456		
5720	Shaft/Bearings/Clutch	\$7,290	35%	\$9,842	2%	\$10,038		
5730	Nacelles/Fairings and Supports	\$6,020	40%	\$8,428	5%	\$8,849		
5740	Compressor Pressure Shell/Stators/IGV/OGV	\$9,180	40%	\$12,852	5%	\$13,495		
5750	Lubrication & Cooling System	\$340	20%	\$408	5%	\$428		
5760	Motors	\$13,000	20%	\$15,600	1%	\$15,756		
5770	Motor Controls	\$39,000	20%	\$46,800	2%	\$47,736		
5780	Gearbox Included With 3530	\$0	0%	\$0	0%	\$0	\$0	
5800	TSWT Elec. Control Systems and Data Acquisition							
5810	Electrical Equipment	\$0	0%	\$0	0%	\$0		
5820	Electrical Materials	\$0	0%	\$0	0%	\$0		
5830	Control Systems (Transferred to 7730)							
5840	Data Acquisition and Data Processing Systems (Transferred to 7230)						\$14,132	
5900	TSWT Test and Validation	\$9,085	10%	\$9,994	1%	\$10,093		
5910	Test and Validation	\$3,635	10%	\$3,999	1%	\$4,038		
5920	Calibration							

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
5A00	Productivity Items							
5A10	Productivity Items	\$6,962	40%	\$9,747	1%	\$9,844	\$9,844	
7000	Operations (LSWT & TSWT)	\$78,493	22%	\$95,853	\$13,027	\$108,880		\$108,880
7100	Calibration						\$25,834	
7110	Auxiliary Process System Calibration	\$0	0%	\$0	0%	\$0		
7120	Airflow Calibration Lab	\$2,785	50%	\$4,178	12%	\$4,679		
7130	Balance Calibration Lab	\$11,130	20%	\$13,356	20%	\$16,027		
7140	Structural Calibration Lab	\$198	10%	\$218	5%	\$229		
7150	Instrument Calibration Lab	\$2,977	10%	\$3,275	10%	\$3,602		
7160	Calibration Hardware - LSWT	\$322	20%	\$386	25%	\$483		
7170	Calibration Hardware - TSWT	\$322	20%	\$386	25%	\$483		
7180	Calibration Model	\$204	30%	\$265	25%	\$332		
7190	External Balance Calibrator	\$0	40%	\$0	20%	\$0		
7200	Data Acquisition System						\$26,479	
7210	Data Acquisition System - Aux. Systems (from 384C)	\$0	0%	\$0	0%	\$0		
7220	Data Acquisition System - LSWT (from 4840)	\$11,353	20%	\$13,624	5%	\$14,305		
7230	Data Acquisition System - TSWT (from 5840)	\$9,662	20%	\$11,594	5%	\$12,174		
7300	Wind Tunnel Balance						\$5,724	
7310	Balance (Internal) LSWT	\$1,696	20%	\$2,035	25%	\$2,544		
7320	Balance (Internal) TSWT	\$2,120	20%	\$2,544	25%	\$3,180		
7400	Models and Models Supports						\$4,909	
7410	Model Handling Equipment (LSWT)(From 3120)	\$271	20%	\$325	6%	\$345		
7420	Model Handling Equipment (TSWT)	\$271	20%	\$325	6%	\$345		
7430	Slings and Struts (LSWT)	\$1,502	20%	\$1,802	16%	\$2,091		
7440	Slings and Struts TSWT	\$1,529	20%	\$1,835	16%	\$2,128		
7450	Acoustic Traverse Rake(Included in 4530)	\$0	0%	\$0	0%	\$0		
7500	Instrumentation						\$25,777	
7510	Test (LSWT)	\$7,757	20%	\$9,308	12%	\$10,425		
7520	Test (TSWT)	\$5,996	20%	\$7,195	12%	\$8,059		
7530	Calibration (LSWT)	\$162	20%	\$194	18%	\$229		
7540	Calibration (TSWT)	\$162	20%	\$194	18%	\$229		
7550	Acoustics (LSWT)	\$0	0%	\$0	0%	\$0		
7560	Acoustics (TSWT)	\$0	0%	\$0	0%	\$0		
7570	Processes (LSWT)	\$1,885	20%	\$2,262	12%	\$2,533		
7580	Process (TSWT)	\$1,699	20%	\$2,039	12%	\$2,283		
7590	Hardware Integ. (LSWT)	\$334	15%	\$384	15%	\$442		
75A0	Hardware Integ. (TSWT)	\$334	15%	\$384	15%	\$442		
75B0	Aux. process Instr. LSWT & BWT	\$727	30%	\$945	20%	\$1,134		
7600	Operations Integration Analysis Plan (Incl. in 8350)						\$0	

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
7610	Productivity (LSWT)	\$0	20%	\$0	0%	\$0		
7620	Productivity (TSWT)	\$0	20%	\$0	0%	\$0		
7630	Maintenance (LSWT)	\$0	20%	\$0	0%	\$0		
7640	Maintenance (TSWT)	\$0	20%	\$0	0%	\$0		
7650	Maintenance - Aux. Syst.	\$0	20%	\$0	0%	\$0		
7660	Instr. Acc. Assessment LSWT & TSWT	\$0	25%	\$0	0%	\$0	\$20,157	
7700	Controls							
7710	Controls - Auxiliary Process Systems (from 3830)	\$1,507	15%	\$1,733	20%	\$2,080		
7720	Controls - LSWT (from 4830)	\$5,757	30%	\$7,484	20%	\$8,981		
7730	Controls - TSWT (from 5830)	\$5,831	30%	\$7,580	20%	\$9,096		
	<b>Subtotal</b>	<b>\$770,273</b>	<b>25%</b>	<b>\$963,455</b>	<b>\$66,415</b>	<b>\$1,029,870</b>	<b>\$1,029,870</b>	<b>\$1,029,870</b>
8000	Management and Support							
8100	Program Management	\$158,120	2%	\$161,379	\$0	\$161,379	\$92,950	\$161,379
8110	Prime Contractor's Program Office	\$74,750	0%	\$74,750	0%	\$74,750		
8120	Operator Training	\$2,800	0%	\$2,800	0%	\$2,800		
8130	Maintenance and Operation Support	\$15,400	0%	\$15,400	0%	\$15,400		
8140	Not used	\$0	0%	\$0	0%	\$0		
8200	Quality Assurance							
8210	Quality Assurance	\$0	0%	\$0	0%	\$0		
8300	Systems Engineering and Integration							
8310	System Engineering and Intergration	\$0	0%	\$0	0%	\$0		
8320	General Engineering	\$0	0%	\$0	0%	\$0		
8330	Performance/System Specifications	\$0	0%	\$0	0%	\$0		
8340	Construction	\$0	0%	\$0	0%	\$0		
8400	Procurement							
8410	Procurement	\$0	0%	\$0	0%	\$0		
8500	Construction Management							
8510	Not used	\$0	0%	\$0	0%	\$0		
8520	Not used	\$0	0%	\$0	0%	\$0		
8530	Not used	\$0	0%	\$0	0%	\$0		
8540	Not used	\$0	0%	\$0	0%	\$0		
8600	Site and Permits							
8700	Field Indirect	\$65,170	5%	\$68,429	0%	\$68,429	\$68,429	
	<b>Total</b>	<b>\$928,393</b>	<b>21%</b>	<b>\$1,124,834</b>	<b>\$66,415</b>	<b>\$1,191,248</b>	<b>\$1,191,248</b>	<b>\$1,191,248</b>
	<b>Project Assessment</b>				<b>6%</b>			<b>\$970,985</b>

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	Profit				9%	\$101,235	\$1,226,069	
	Bond				0.8%	\$9,809	\$1,235,877	
	Cost Adjustment		7	3.5%	27%	\$336,504	\$1,572,381	
	Construction Cost Estimate						\$1,572,381	
	Contingency				10%	\$157,238	\$1,729,619	
	SIES(Construction Management)				6%	\$103,777	\$1,833,396	
	SIES(Engineering Support)				2%	\$34,592	\$1,867,988	
	Total Construction Budget Estimate						\$1,867,988	
	PER				2%	\$37,360	\$1,905,348	
	Government Project Management				10%	\$96,346	\$2,001,694	
	Studies					\$11,460	\$2,013,154	
	Design(Including Design Management)					\$82,665	\$2,095,818	
	Real Estate					\$0	\$2,095,818	
	Other Burden Expense					\$0	\$2,095,818	
	<b>Project Total</b>					<b>\$2,095,818</b>		<b>\$2,095,818</b>





WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
1380	Steam System	\$0	0%	\$0	0%	\$0		
1400	Yard Electrical System						\$58,634	
1410	Electrical Equipment	\$48,100	15%	\$55,315	6%	\$58,634		
1420	Electrical Material (Included in 4110)	\$0	0%	\$0	0%	\$0	\$1,268	
1500	Other Electrical Systems							
1510	Lighting Systems	\$71	20%	\$85	6%	\$90		
1520	Communication Systems	\$209	20%	\$251	6%	\$266		
1530	Security Systems	\$369	20%	\$443	6%	\$469		
1540	Grounding	\$29	20%	\$35	6%	\$37		
1550	Cathodic Protection	\$101	20%	\$121	6%	\$128		
1560	Lightning Protection	\$101	20%	\$121	6%	\$128		
1570	Freeze Protection	\$57	20%	\$68	6%	\$73		
1580	Environmental Monitoring	\$24	20%	\$29	6%	\$31		
1590	DC Power for Instrumentation	\$36	20%	\$43	6%	\$46		
2000	Buildings	\$68,381	20%	\$82,326	\$4,755	\$87,081		\$87,081
2100	Test Preparations/Control Building						\$34,689	
2110	LSWT/...Prep/Control	\$27,271	20%	\$32,725	6%	\$34,689		
2120	TSWT/...Prep/Control							
2200	Wind Tunnel Drive Buildings						\$7,770	
2210	LSWT/TSWT Drive Building	\$1,438	15%	\$1,654	8%	\$1,786		
2220	Not Used	\$4,818	15%	\$5,541	8%	\$5,984		
2300	Support Buildings						\$31,491	
2310	Model Shop And Warehouse	\$14,343	20%	\$17,212	6%	\$18,244		
2320	Support Shop Building(Included in 2110)	\$0	0%	\$0	0%	\$0		
2330	Engineering Office	\$2,051	20%	\$2,461	8%	\$2,658		
2340	Guard House	\$205	10%	\$226	6%	\$239		
2350	Outfitting	\$8,625	20%	\$10,350	0%	\$10,350		
2400	Utility Buildings						\$13,131	
2410	WT Press/Vac Building	\$3,401	20%	\$4,081	8%	\$4,408		
2420	Not Used	\$0	0%	\$0	0%	\$0		
2430	Heat Pump System Equipment Building	\$0	0%	\$0	0%	\$0		
2440	HVAC Chiller Building	\$0	0%	\$0	0%	\$0		
2450	Utility Tunnels	\$6,021	30%	\$7,827	8%	\$8,453		
2460	Other Minor Buildings	\$208	20%	\$250	8%	\$270		
2470	Motor Pool Vehicles (Transferred to 2350)	\$0	0%	\$0	0%	\$0		
3000	Auxiliary Process Systems	\$103,530	19%	\$123,189	\$6,542	\$129,731		\$129,731
3100	Test Model And Cart Transport						\$2,912	
3110	LSWT Shuttle Cart	\$2,000	30%	\$2,600	12%	\$2,912		
3120	TSWT Shuttle Cart	\$0	0%	\$0	0%	\$0		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
3200	Wind Tunnel Pressurization/Vacuum System							
3210	Compressors, Drifters, Pumps, Etc.	\$31,281	20%	\$37,537	3%	\$38,663	\$82,994	
3220	Heaters And Coolers	\$615	20%	\$738	5%	\$775		
3230	Drier System	\$6,485	20%	\$7,782	1%	\$7,860		
3240	Filters	\$1,900	20%	\$2,280	1%	\$2,303		
3250	Distribution Piping	\$10,588	20%	\$12,706	10%	\$13,976		
3260	Storage Tanks	\$12,361	15%	\$14,215	6%	\$15,068		
3270	Muffler Towers	\$1,455	15%	\$1,673	6%	\$1,774		
3280	Vacuum System	\$2,209	10%	\$2,430	6%	\$2,576		
3400	Cooling System						\$12,997	
3410	Cooling Towers	\$4,835	20%	\$5,802	1%	\$5,860		
3420	Cw Circ Pumps & Motors	\$2,270	20%	\$2,724	1%	\$2,751		
3430	Miscellaneous Equipment	\$138	20%	\$166	8%	\$179		
3440	Distribution System Piping	\$3,246	20%	\$3,895	8%	\$4,207		
3500	Not Used							
3600	Miscellaneous Support Systems							
3610	Tunnel Cleaning System	\$3,600	30%	\$4,680	10%	\$5,148	\$20,773	
3620	Calibration System (High Pressure Air/Model Prop.)	\$11,837	20%	\$14,204	10%	\$15,625		
3630	Compressor Blade Handling System(Transferred to	\$0	0%	\$0	0%	\$0		
3700	Scavenging And Fire Suppression System							
3710	Combustible Gas Scavenging System (Not used)	\$0	0%	\$0	0%	\$0	\$0	
3720	Tunnel Fire Suppression System (Not used)	\$0	0%	\$0	0%	\$0		
3800	Aux. Electr Control Systems And Data Acquisition						\$4,262	
3810	Electrical Equipment	\$3,496	15%	\$4,020	6%	\$4,262		
3820	Electrical Bulks(Included in 3810)	\$0	0%	\$0	0%	\$0		
3830	Control System (Transferred to 7710)	\$0	0%	\$0	0%	\$0		
3840	Data Acquisition And Processing Systems (Transfer	\$0	0%	\$0	0%	\$0		
3900	Auxiliary Test And Validation						\$2,516	
3910	Test And Validation	\$1,510	10%	\$1,661	1%	\$1,678		
3920	Calibration	\$755	10%	\$831	1%	\$839		
3A00	Productivity Provisions							
3A10	Productivity Provisions	\$2,949	10%	\$3,244	1%	\$3,277	\$3,277	
4000	Low Speed Wind Tunnel	\$212,537	30%	\$275,926	\$19,805	\$295,731		\$295,731
4100	LSWT Enclosure							
4110	Foundation	\$8,661	20%	\$10,393	8%	\$11,225	\$22,680	
4120	Enclosure	\$7,919	20%	\$9,503	8%	\$10,263		
4130	Acoustic Insulation	\$317	20%	\$380	6%	\$403		
4140	Electrical Services	\$326	15%	\$375	6%	\$397		
4150	Mechanical Services	\$321	15%	\$369	6%	\$391		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
4200	LSWT Pressure Shell							
4210	LSWT Support Foundation( Incl. In 4110)	\$0	0%	\$0	0%	\$0	\$111,829	
4220	LSWT Support Structure	\$9,013	25%	\$11,266	4%	\$11,717		
4230	LSWT Pressure Shell	\$77,009	25%	\$96,261	4%	\$100,112		
4300	LSWT Pressure Isolation System						\$8,417	
4310	LSWT Isolation Valves	\$4,500	60%	\$7,200	15%	\$8,280		
4320	LSWT Personnel Access (Not used)	\$0	0%	\$0	0%	\$0		
4330	Hydraulic Power Unit	\$100	30%	\$130	5%	\$137		
4340	Exhaust Silencer (Transferred to 3270)	\$0	0%	\$0	0%	\$0		
4400	LSWT Flow Internals						\$35,517	
4410	Turning Vanes	\$4,400	30%	\$5,720	15%	\$6,578		
4420	Honeycomb	\$2,040	30%	\$2,652	15%	\$3,050		
4430	Screens	\$1,900	30%	\$2,470	15%	\$2,841		
4440	Internal Heat Exchanger	\$6,500	20%	\$7,800	5%	\$8,190		
4450	Settling Chamber Liner	\$8,619	30%	\$11,205	15%	\$12,885		
4460	Plenum Evacuation System (Not used)	\$0	0%	\$0	0%	\$0		
4470	Gas Manifolding(Not used)	\$0	0%	\$0	0%	\$0		
4480	High Speed Diffuser	\$1,220	30%	\$1,586	15%	\$1,824		
4490	Acoustic Treatment for nacelles	\$0	0%	\$0	0%	\$0		
44A0	Compressor FOD Protection	\$100	30%	\$130	15%	\$150		
44B0	Acoustic Baffles (Not used)	\$0	0%	\$0	0%	\$0		
44C0	Tunnel Cleaning System(Transferred to 3610)	\$0	0%	\$0	0%	\$0	\$41,758	
4500	Test Plenum							
4510	Subsonic Nozzle(Transferred to 4450)	\$0	0%	\$0	0%	\$0		
4520	Flutter Test Section (Not In Concept )	\$0	0%	\$0	0%	\$0		
4530	Open Jet Test Section	\$0	0%	\$0	0%	\$0		
4540	Moveable Plenum	\$6,506	40%	\$9,108	15%	\$10,475		
4550	Not used	\$0	0%	\$0	0%	\$0		
4560	Observation System	\$350	40%	\$490	15%	\$564		
4570	Test Section Carts	\$16,000	60%	\$25,600	20%	\$30,720		
4580	Preparation Hall Shuttle Cart	\$0	0%	\$0	0%	\$0		
4590	Anechoic Chamber	\$0	0%	\$0	0%	\$0		
4600	Test Support Equipment						\$10,755	
4610	Vertical Strut Assembly (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
4620	Floor Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4630	Half Model Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4640	Moving Ground Plane (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
4650	Elevated Ground Plane	\$1,200	50%	\$1,800	15%	\$2,070		
4660	Inverted Ground Plane	\$1,200	50%	\$1,800	15%	\$2,070		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
4670	Sling (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4680	External Balance	\$4,500	40%	\$6,300	5%	\$6,615		
4700	Compressor and Drive System						\$41,660	
4710	Rotor Hub/Blades	\$7,800	30%	\$10,140	3%	\$10,444		
4720	Shaft/Bearings/Clutch	\$2,360	25%	\$2,950	2%	\$3,009		
4730	Nacelles/Fairings and Supports	\$1,760	30%	\$2,288	5%	\$2,402		
4740	Gearbox	\$0	0%	\$0	0%	\$0		
4750	Lubrication and Cooling System	\$160	20%	\$192	5%	\$202		
4760	Motor	\$3,000	20%	\$3,600	1%	\$3,636		
4770	Motor Drive Controls	\$9,000	20%	\$10,800	2%	\$11,016		
4780	Compressor Pressure Shell/Stators/IGV/OGV	\$7,020	50%	\$10,530	4%	\$10,951		
4800	Electrical, Controls System and Data Acquisition						\$0	
4810	Electrical Equipment (Transferred to 1410)	\$0	0%	\$0	0%	\$0		
4820	Electrical Materials (Transferred to 1420)	\$0	0%	\$0	0%	\$0		
4830	Control and Instrumentation (Transferred to 7720)							
4840	Data Acquisition and Processing Systems (Transferred to 7720)							
4900	Test & Validation						\$12,382	
4910	Test and Validation	\$7,960	10%	\$8,756	1%	\$8,844		
4920	Calibration	\$3,185	10%	\$3,504	1%	\$3,539		
4A00	Productivity Provisions						\$10,734	
4A10	Productivity Provisions	\$7,591	40%	\$10,628	1%	\$10,734		
5000	Transonic Wind Tunnel (TSWT)	\$251,742	28%	\$322,063	\$18,482	\$340,545		\$340,545
5100	TSWT Enclosure						\$21,039	
5110	Foundation	\$8,051	20%	\$9,661	8%	\$10,434		
5120	Enclosure	\$7,333	20%	\$8,800	8%	\$9,504		
5130	Acoustic Insulation	\$284	20%	\$341	8%	\$361		
5140	Electrical Services	\$306	15%	\$352	8%	\$373		
5150	Mechanical Services	\$301	15%	\$346	8%	\$367		
5200	Pressure Vessels						\$54,541	
5210	Foundations	\$0	0%	\$0	0%	\$0		
5220	Shell Support System	\$4,515	25%	\$5,644	5%	\$5,926		
5230	TSWT Pressure Shell	\$37,040	25%	\$46,300	5%	\$48,615		
5300	Pressure Isolation System						\$8,442	
5310	TSWT Isolation Valves	\$3,570	100%	\$7,140	15%	\$8,211		
5320	TSWT Personnel Access	\$0	0%	\$0	0%	\$0		
5330	Hydraulic Power Unit	\$150	40%	\$210	10%	\$231		
5400	TSWT Flow Internals						\$66,327	
5410	Turning Vanes	\$4,275	20%	\$5,130	10%	\$5,643		
5420	Honeycomb	\$1,019	30%	\$1,325	10%	\$1,457		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
5430	Screens	\$1,051	30%	\$1,366	10%	\$1,503		
5440	Internal Heat Exchanger	\$7,105	30%	\$9,237	10%	\$10,160		
5450	Settling Chamber Liner	\$2,040	40%	\$2,856	10%	\$3,142		
5460	Plenum Evacuation System	\$23,240	20%	\$27,888	5%	\$29,282		
5470	Acoustic Baffles	\$600	20%	\$720	15%	\$828		
5480	Flexible Nozzle	\$2,500	30%	\$3,250	15%	\$3,738		
5490	Compressor FOD Protection	\$3,400	20%	\$4,080	15%	\$4,692		
54A0	Choke System	\$3,100	30%	\$4,030	20%	\$4,836		
54B0	High Speed Diffuser Liner	\$650	40%	\$910	15%	\$1,047		
54C0	Ejection System	\$0	0%	\$0	0%	\$0		
5500	TSWT Test Plenum						\$36,056	
5510	Test Section	\$17,560	40%	\$24,584	12%	\$27,534		
5520	Moveable Plenum	\$5,500	30%	\$7,150	15%	\$8,223		
5530	Observation System	\$200	30%	\$260	15%	\$299		
5540	Preparation Hail Shuttle Cart	\$0	0%	\$0	0%	\$0		
5600	TSWT Test Support Equipment						\$6,406	
5610	Model Support (Incl. in 5510)	\$0	0%	\$0	0%	\$0		
5620	Floor Mounts (Interface only)	\$0	0%	\$0	0%	\$0		
5630	Half Model Mounts(Interface only)	\$0	0%	\$0	0%	\$0		
5640	Stings and Booms(Incl. in 7440)	\$0	0%	\$0	0%	\$0		
5650	External Balance	\$4,400	40%	\$6,160	4%	\$6,406		
5660	Other Test Support Equipment(Incl. in 7740)	\$0	0%	\$0	0%	\$0		
5700	TSWT Compressor Drive System						\$123,758	
5710	Rotor Hub/Blades	\$19,040	40%	\$26,656	3%	\$27,456		
5720	Shaft/Bearings/Clutch	\$7,290	35%	\$9,842	2%	\$10,038		
5730	Nacelles/Fairings and Supports	\$6,020	40%	\$8,428	5%	\$8,849		
5740	Compressor Pressure Shell/Stators/IGV/OGV	\$9,180	40%	\$12,852	5%	\$13,495		
5750	Lubrication & Cooling System	\$340	20%	\$408	5%	\$428		
5760	Motors	\$13,000	20%	\$15,600	1%	\$15,756		
5770	Motor Controls	\$39,000	20%	\$46,800	2%	\$47,736		
5780	Gearbox Included With 3530	\$0	0%	\$0	0%	\$0		
5800	TSWT Elec. Control Systems and Data Acquisition						\$0	
5810	Electrical Equipment	\$0	0%	\$0	0%	\$0		
5820	Electrical Materials	\$0	0%	\$0	0%	\$0		
5830	Control Systems (Transferred to 7730)							
5840	Data Acquisition and Data Processing Systems (Transferred to 7230)							
5900	TSWT Test and Validation, Calibration						\$14,132	
5910	Test and Validation	\$9,085	10%	\$9,994	1%	\$10,093		
5920	Calibration	\$3,635	10%	\$3,999	1%	\$4,038		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
5A00	Productivity Items							
5A10	Productivity Items	\$6,962	40%	\$9,747	1%	\$9,844	\$9,844	
7000	Operations (LSWT & TSWT)	\$78,493	22%	\$95,853	\$13,027	\$108,880		\$108,880
7100	Calibration						\$25,834	
7110	Auxiliary Process System Calibration	\$0	0%	\$0	0%	\$0		
7120	Airflow Calibration Lab	\$2,785	50%	\$4,178	12%	\$4,679		
7130	Balance Calibration Lab	\$11,130	20%	\$13,356	20%	\$16,027		
7140	Structural Calibration Lab	\$198	10%	\$218	5%	\$229		
7150	Instrument Calibration Lab	\$2,977	10%	\$3,275	10%	\$3,602		
7160	Calibration Hardware - LSWT	\$322	20%	\$386	25%	\$483		
7170	Calibration Hardware - TSWT	\$322	20%	\$386	25%	\$483		
7180	Calibration Model	\$204	30%	\$265	25%	\$332		
7190	External Balance Calibrator	\$0	40%	\$0	20%	\$0		
7200	Data Acquisition System						\$26,479	
7210	Data Acquisition System - Aux. Systems (from 384C)	\$0	0%	\$0	0%	\$0		
7220	Data Acquisition System - LSWT (from 4840)	\$11,353	20%	\$13,624	5%	\$14,305		
7230	Data Acquisition System - TSWT (from 5840)	\$9,662	20%	\$11,594	5%	\$12,174		
7300	Wind Tunnel Balance						\$5,724	
7310	Balance (Internal) LSWT	\$1,696	20%	\$2,035	25%	\$2,544		
7320	Balance (Internal) TSWT	\$2,120	20%	\$2,544	25%	\$3,180		
7400	Models and Models Supports						\$4,909	
7410	Model Handling Equipment (LSWT)(From 3120)	\$271	20%	\$325	6%	\$345		
7420	Model Handling Equipment (TSWT)	\$271	20%	\$325	6%	\$345		
7430	Stings and Struts (LSWT)	\$1,502	20%	\$1,802	16%	\$2,091		
7440	Stings and Struts TSWT	\$1,529	20%	\$1,835	16%	\$2,128		
7450	Acoustic Traverse Rake(Included in 4530)	\$0	0%	\$0	0%	\$0		
7500	Instrumentation						\$25,777	
7510	Test (LSWT)	\$7,757	20%	\$9,308	12%	\$10,425		
7520	Test (TSWT)	\$5,996	20%	\$7,195	12%	\$8,059		
7530	Calibration (LSWT)	\$162	20%	\$194	18%	\$229		
7540	Calibration (TSWT)	\$162	20%	\$194	18%	\$229		
7550	Acoustics (LSWT)	\$0	0%	\$0	0%	\$0		
7560	Acoustics (TSWT)	\$0	0%	\$0	0%	\$0		
7570	Processes (LSWT)	\$1,885	20%	\$2,262	12%	\$2,533		
7580	Process (TSWT)	\$1,699	20%	\$2,039	12%	\$2,283		
7590	Hardware Integ. (LSWT)	\$334	15%	\$384	15%	\$442		
75A0	Hardware Integ. (TSWT)	\$334	15%	\$384	15%	\$442		
75B0	Aux. process Instr. LSWT & BWT	\$727	30%	\$945	20%	\$1,134		
7600	Operations Integration Analysis Plan (Incl. in 8350)						\$0	

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
7610	Productivity (LSWT)	\$0	20%	\$0	0%	\$0		
7620	Productivity (TSWT)	\$0	20%	\$0	0%	\$0		
7630	Maintenance (LSWT)	\$0	20%	\$0	0%	\$0		
7640	Maintenance (TSWT)	\$0	20%	\$0	0%	\$0		
7650	Maintenance - Aux. Syst.	\$0	20%	\$0	0%	\$0		
7660	Instr. Acc. Assessment LSWT & TSWT	\$0	25%	\$0	0%	\$0		
7700	Controls						\$20,157	
7710	Controls - Auxiliary Process Systems (from 3830)	\$1,507	15%	\$1,733	20%	\$2,080		
7720	Controls - LSWT (from 4830)	\$5,757	30%	\$7,484	20%	\$8,981		
7730	Controls - TSWT (from 5830)	\$5,831	30%	\$7,580	20%	\$9,096		
	<b>Subtotal</b>	<b>\$770,273</b>	<b>25%</b>	<b>\$963,455</b>	<b>\$66,415</b>	<b>\$1,029,870</b>	<b>\$1,029,870</b>	<b>\$1,029,870</b>
					7%			
8000	Management and Support							\$138,629
8100	Program Management							
8110	Prime Contractor's Program Office	\$52,000	0%	\$52,000	0%	\$52,000		
8120	Operator Training	\$2,800	0%	\$2,800	0%	\$2,800		
8130	Maintenance and Operation Support	\$15,400	0%	\$15,400	0%	\$15,400		
8140	Not used	\$0	0%	\$0	0%	\$0		
8200	Quality Assurance							\$0
8210	Quality Assurance	\$0	0%	\$0	0%	\$0		
8300	Systems Engineering and Integration							\$0
8310	System Engineering and Integration	\$0	0%	\$0	0%	\$0		
8320	General Engineering	\$0	0%	\$0	0%	\$0		
8330	Performance/System Specifications	\$0	0%	\$0	0%	\$0		
8340	Construction	\$0	0%	\$0	0%	\$0		
8400	Procurement							\$0
8410	Procurement	\$0	0%	\$0	0%	\$0		
8500	Construction Management							\$0
8510	Not used	\$0	0%	\$0	0%	\$0		
8520	Not used	\$0	0%	\$0	0%	\$0		
8530	Not used	\$0	0%	\$0	0%	\$0		
8540	Not used	\$0	0%	\$0	0%	\$0		
8600	Site and Permits							
8700	Field Indirect	\$65,170	5%	\$68,429	0%	\$68,429		
	<b>Total</b>	<b>\$905,643</b>	<b>22%</b>	<b>\$1,102,084</b>	<b>\$66,415</b>	<b>\$1,168,498</b>	<b>\$1,168,498</b>	<b>\$1,168,498</b>
	<b>Project Assessment</b>				6%			<b>\$787,678</b>

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	Profit				0%	\$0	\$1,102,084	
	Bond				0.8%	\$8,817	\$1,110,900	
	Cost Adjustment		6	3.5%	23%	\$254,680	\$1,365,580	
	Construction Cost Estimate						\$1,365,580	
	Contingency				20%	\$273,116	\$1,638,696	
	SIES(Construction Management)				0%	\$98,322	\$1,737,018	
	SIES(Engineering Support)				2%	\$32,774	\$1,769,792	
	Total Construction Budget Estimate						\$1,769,792	
	PER				0%	\$0	\$1,769,792	
	Government Project Management					\$28,645	\$1,798,437	
	Studies					\$8,660	\$1,807,097	
	Design(Including Design Management)					\$82,665	\$1,889,761	
	Real Estate					\$0	\$1,889,761	
	Other Burden Expense					\$0	\$1,889,761	
	Project Total					\$1,889,761		\$1,889,761

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**National Wind Tunnel Complex**  
**Joint Industry Government Team**  
**Appendix 2**  
**The Boeing Company**  
**Concept A Cost Estimates**







		Boeing					
		Original(Dec. 91 X 2yr. @ 3.5%)			JIGT		
WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Engineering Estimate	Risk Factor	Const. Cost
2420	Not Used						
2430	Heat Pump System Equipment Building			\$0			\$0
2440	HVAC Chiller Building			\$192			\$192
2450	Utility Tunnels			\$200			\$200
2460	Other Minor Buildings			\$3,257			\$3,257
2470	Motor Pool Vehicles (Transferred to 2350)			\$214			\$214
3000	Auxiliary Process Systems			\$0	JIGT Adjustments		\$10,541
3100	Test Model And Cart Transport			\$45,136			\$111,207
3110	LSWT/TSWT Shuttle Carts						
3120	TSWT Shuttle Carts (Transferred to 3110)			\$0			\$0
3200	Wind Tunnel Pressurization/Vacuum System			\$0			\$0
3210	Compressors, Driers, Pumps, Etc.						
3220	Heaters And Coolers			\$24,274			\$24,274
3230	Drier System			\$0			\$0
3240	Filters			\$0			\$0
3250	Distribution Piping			\$0			\$0
3260	Storage Tanks			\$0			\$0
3270	Muffler Towers			\$191			\$191
3280	Vacuum System			\$0			\$0
3400	Cooling System			\$0			\$0
3410	Cooling Towers						
3420	Cw Circ Pumps & Motors			\$4,944			\$4,944
3430	Miscellaneous Equipment			\$47			\$47
3440	Distribution System Piping			\$0			\$0
3500	Not Used			\$0			\$0
3600	Miscellaneous Support Systems			\$0			\$0
3610	Tunnel Cleaning System						
3620	Air System(4500psi)			\$214			\$214
3630	Compressor Blade Handling System(Transferred to 4000 &5000)			\$2,009			\$2,009
3700	Scavenging And Fire Suppression System			\$161			\$161
3710	Combustible Gas Scavenging System (Not in Concept A)						
3720	Tunnel Fire Suppression System (Not in Concept A)			\$0			\$0
3800	Aux. Electr Control Systems And Data Acquisition			\$0	JIGT ADJUSTMENTS		\$56,646
3810	Electrical Equipment			\$2,769			\$2,769



		Boeing					
		Original(Dec. 91 X 2yr. @ 3.5%)				JIGT	
WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Engineering Estimate	Risk Factor	Const. Cost
4490	Acoustic Treatment for nacelles (Not in Concept A)			\$456			\$456
44A0	Compressor FOD Protection (Not Used)			\$0			\$0
44B0	Acoustic Baffles (Not in Concept A)			\$0			\$0
44C0	Tunnel Cleaning System (Transferred to 3610)			\$0			\$0
4500	Test Plenum						
4510	Subsonic Nozzle (Transferred to 4450)			\$2,082			\$2,082
4520	Flutter Test Section (Not in Concept A)			\$0			\$0
4530	Open Jet Test Section			\$1,292			\$1,292
4540	Moveable Plenum			\$268			\$268
4550	Not used			\$0			\$0
4560	Observation System			\$0			\$0
4570	Test Section Carts			\$8,566			\$8,566
4580	Preparation Hall Shuttle Cart (Transferred to 3110)			\$1,071			\$1,071
4590	Anechoic Chamber (Not in Concept A)			\$0			\$0
4600	Test Support Equipment						
4610	Vertical Strut Assembly (Transferred to 4570)			\$0			\$0
4620	Floor Mount (Transferred to 7430)			\$0			\$0
4630	Half Model Mount (Transferred to 7430)			\$0			\$0
4640	Moving Ground Plane (Transferred to 4570)			\$0			\$0
4650	Elevated Ground Plane			\$381			\$381
4660	Inverted Ground Plane			\$0			\$0
4670	Sting (Transferred to 7430)			\$0			\$0
4680	External Balance			\$5,275			\$5,275
4700	Compressor and Drive System						
4710	Rotor Hub/Blades			\$10,267			\$10,267
4720	Shaft/Bearings/Clutch			\$4,009			\$4,009
4730	Nacelles/Fairings and Supports			\$2,907			\$2,907
4740	Gearbox			\$0			\$0
4750	Lubrication and Cooling System			\$109			\$109
4760	Motor			\$13,659			\$13,659
4770	Motor Drive Controls			\$0			\$0
4780	Compressor Pressure Shell/Stators/IGV/OGV			\$0			\$0
4800	Electrical, Controls System and Data Acquisition						
4810	Electrical Equipment			\$724			\$724
4820	Electrical Materials			\$1,307			\$1,307

		Boeing					
		Original(Dec. 91 X 2yr. @ 3.5%)			JIGT		
WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Engineering Estimate	Risk Factor	Const. Cost
4830	Control and Instrumentation (Transferred to 7720)			\$0			\$0
4840	Data Acquisition and Processing Systems (Transferred to 7720)			\$129			\$129
4900	Test & Validation						
4910	Test and Validation			\$1,500			\$1,500
4920	Calibration			\$357			\$357
4A00	Productivity Provisions						
4A10	Productivity Provisions			\$0			\$0
5000	Transonic Wind Tunnel (TSWT)			\$225,216			\$234,886
5100	TSWT Acoustic Enclosure						
5110	Foundation			\$2,834			\$2,834
5120	Enclosure			\$1,319			\$1,319
5130	Acoustic Insulation			\$0			\$0
5140	Electrical Services			\$130			\$130
5150	Mechanical Services			\$0			\$0
5200	Pressure Vessels						
5210	Foundations (Included in 5110)			\$0			\$0
5220	Shell Support System			\$2,844			\$2,844
5230	TSWT Pressure Shell			\$33,949			\$33,949
5300	Pressure Isolation System						
5310	TSWT Isolation Valves			\$694			\$694
5320	TSWT Personnel Access DELETED			\$2,475			\$2,475
5330	Hydraulic Power Unit			\$107			\$107
5400	TSWT Flow Internals						
5410	Turning Vanes			\$1,926			\$1,926
5420	Honeycomb			\$1,404			\$1,404
5430	Screens			\$0			\$0
5440	Internal Heat Exchanger			\$3,878			\$3,878
5450	Settling Chamber Liner			\$1,642			\$1,642
5460	Plenum Evacuation System			\$20,547			\$20,547
5470	Acoustic Baffles			\$536			\$536
5480	Contouring Nozzle			\$3,280			\$3,280
5490	Compressor FOD Protection			\$0			\$0
54A0	Choke System			\$1,029			\$1,029
54B0	High Speed Diffuser Liner			\$938			\$938

		Boeing					
		Original(Dec. 91 X 2yr. @ 3.5%)			JIGT		
WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Engineering Estimate	Risk Factor	Const. Cost
5400	Tunnel Cleaning System (Not Incl.)						
5500	TSWT Test Plenum			\$322			\$322
5510	Test Section						
5520	Moveable Plenum			\$9,234			\$9,234
5530	Observation System			\$268			\$268
5540	Preparation Hall Shuttle Cart			\$536			\$536
5600	TSWT Test Support Equipment			\$1,071			\$1,071
5610	Model Support (Incl. in 5510)						
5620	Floor Mounts (Interface only)			\$3,442			\$3,442
5630	Half Model Mounts(Interface only)			\$0			\$0
5640	Stings and Booms(Incl. in 7440)			\$0			\$0
5650	External Balance			\$0			\$0
5660	Other Test Support Equipment(Incl. in 7740)			\$5,190			\$5,190
5700	TSWT Compressor Drive System			\$0	JIGT Adjustments		\$8,291
5710	Rotor Hub/Blades						
5720	Shaft/Bearings/Clutch			\$46,002			\$46,002
5730	Nacelles/Fairings and Supports			\$9,952			\$9,952
5740	Compressor Pressure Shell/Stators/IGV/OGV			\$0			\$0
5750	Lubrication & Cooling System			\$0			\$0
5760	Motors			\$1,071			\$1,071
5770	Motor Controls			\$10,694			\$10,694
5780	Gearbox Included With 3530			\$21,446			\$21,446
5800	TSWT Elec. Control Systems and Data Acquisition			\$0			\$0
5810	Electrical Equipment						
5820	Electrical Materials			\$2,726			\$2,726
5830	Control Systems (Transferred to 7730)			\$1,510			\$1,510
5840	Data Acquisition and Data Processing Systems (Transferred to 7230)			\$0			\$0
5900	TSWT Test and Validation, Calibration			\$129			\$129
5910	Test and Validation						
5920	Calibration			\$1,903			\$1,903
5A00	Productivity Items			\$357			\$357
5A00	Productivity Items			\$0			\$0
7000	Operations (LSWT & TSWT)			\$89,004			\$89,004
7100	Calibration						\$112,905

		Boeing					
		Original(Dec. 91 X 2yr. @ 3.5%)				JIGT	
WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Engineering Estimate	Risk Factor	Const. Cost
7110	Auxiliary Process System Calibration			\$0			\$0
7120	Airflow Calibration Lab			\$7,033			\$7,033
7130	Balance Calibration Lab			\$5,860			\$5,860
7140	Structural Calibration Lab			\$0			\$0
7150	Instrument Calibration Lab			\$2,678			\$2,678
7160	Calibration Hardware - LSWT			\$664			\$664
7170	Calibration Hardware - TSWT			\$182			\$182
7180	Calibration Model			\$2,957			\$2,957
7190	External Balance Calibrator			\$0			\$0
7200	Data Acquisition System						
7210	Data Acquisition System - Aux. Systems (from 3840)			\$214			\$214
7220	Data Acquisition System - LSWT (from 4840)			\$8,034			\$8,034
7230	Data Acquisition System - TSWT (from 5840)			\$32,137			\$32,137
7300	Wind Tunnel Balance						
7310	Balance (Internal) LSWT			\$976			\$976
7320	Balance (Internal) TSWT			\$3,524			\$3,524
7400	Models and Models Supports						
7410	Model Handling Equipment (LSWT)(From 3120)			\$643			\$643
7420	Model Handling Equipment (TSWT)			\$514			\$514
7430	Stings and Struts (LSWT)			\$630			\$630
7440	Stings and Struts TSWT			\$512			\$512
7450	Acoustic Traverse Rake			\$0			\$0
7500	Instrumentation						
7510	Test (LSWT)			\$0	JIGT Adjustments		\$23,901
7520	Test (TSWT)			\$0			\$0
7530	Calibration (LSWT)			\$0			\$0
7540	Calibration (TSWT)			\$0			\$0
7550	Acoustics (LSWT)			\$0			\$0
7560	Acoustics (TSWT)			\$0			\$0
7570	Processes (LSWT)			\$0			\$0
7580	Process (TSWT)			\$0			\$0
7590	Hardware Integ. (LSWT)			\$0			\$0
75A0	Hardware Integ. (TSWT)			\$0			\$0
75B0	Aux. process Instr, LSWT & BWT			\$0			\$0



		Boeing					
		Original(Dec. 91 X 2yr. @ 3.5%)			JIGT		
WBS	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Engineering Estimate	Risk Factor	Const. Cost
No.							
8600	Site and Permits			\$3,964			\$3,964
8700	Field Indirect			\$50,307			\$50,307
	<b>Total</b>			<b>\$714,916</b>			<b>\$869,222</b>
	<b>Project Assessment</b>			<b>\$311,441</b>			<b>\$366,891</b>
	Profit			\$10,738			\$12,973
	Bond			\$0			\$0
	Cost Adjustment (7 yr. @ 3.5%)			\$0			\$0
	Construction Cost Estimate						
	Contingency			\$171,059			\$206,019
	SIES			\$19,711			\$19,711
	<b>Total Construction Budget Estimate</b>						
	PER			\$0			\$0
	Government Project Management			\$33,636			\$39,419
	Studies			\$0			\$0
	Design(Including Design Management)			\$76,297			\$88,769
	Real Estate			\$0			\$0
	Other Burden Expense			\$0			\$0
	<b>Project Total</b>			<b>\$1,026,357</b>			<b>\$1,236,113</b>

**National Wind Tunnel Complex**  
**Joint Industry Government Team**  
**Appendix 3**  
**Concept D - Option 5**  
**Cost Estimate Data Sheets**

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**NATIONAL WIND TUNNEL COMPLEX**  
**NATIONAL CONSENSUS REQUIREMENTS**  
**CONCEPT D Option 5**  
 COST ESTIMATE  
 (Dollars in Thousands)

<u>WBS</u>	<u>DESCRIPTION</u>	Government Procurement	Government Procurement	Consortium Procurement
		9/3/93	JIGT(2/25/94)	2/25/93
		<u>Estimate</u>	<u>Estimate</u>	<u>Estimate</u>
1000	Site And Infrastructure	\$59,678	\$58,270	\$58,270
2000	Buildings	\$103,058	\$103,074	\$103,074
3000	Auxiliary Process System	\$148,947	\$114,408	\$114,408
4000	Low Speed Wind Tunnel	\$408,948	\$386,622	\$386,622
5000	Transonic Speed Wind Tunnel	\$352,514	\$320,997	\$320,997
7000	Operations (LSWT & TSWT)	\$106,479	\$89,056	\$89,056
8000	Management And Support	\$198,671	\$158,120	\$135,370
	<b>Engineering Estimate</b>	<b>\$1,378,295</b>	<b>\$1,230,547</b>	<b>\$1,207,797</b>
	<b>Risk</b>	<b>\$333,689</b>	<b>\$294,394</b>	<b>\$294,394</b>
	<b>Subtotal</b>	<b>\$1,711,984</b>	<b>\$1,524,941</b>	<b>\$1,502,191</b>
	Profit	\$171,198	\$152,494	\$0
	Bond	\$18,832	\$16,774	\$12,018
	Escalation	\$513,544	\$461,298	\$347,140
	Contingency	\$241,556	\$215,551	\$372,270
	Construction Management(6%)	\$159,427	\$142,263	\$134,017
	Engineering Support(2%)	\$53,142	\$47,421	\$44,672
	<b>Total Construction Budget</b>	<b>\$2,869,683</b>	<b>\$2,560,743</b>	<b>\$2,412,308</b>
	PER	\$46,000	\$46,000	\$0
	Government PM	\$151,005	\$136,356	\$28,645
	Studies	\$38,523	\$11,460	\$8,660
	Design	\$118,181	\$100,800	\$100,800
	<b>PROJECT TOTAL</b>	<b>\$3,223,393</b>	<b>\$2,855,359</b>	<b>\$2,550,412</b>

National Wind Tunnel Complex									
FSO Concept D Option 5 (9/3/93)									
(With Corner Fillets LSWT & 3 Stage Compressor/Simplified Nozzle TSWT)									
Draft Facility Cost Estimate									
(Dollars in Thousand)									
Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
1	1000	Site And Infrastructure	\$59,678	15%	\$68,808	\$4,050	\$72,857		\$72,857
	1100	Site Preparation						\$72	
	1110	Investigation (Design Process Only)	\$0	0%	\$0	\$0	\$0		\$0
	1120	Clearing And Grubbing	\$46	50%	\$69	5%	\$72		\$72
	1130	Demolition	\$0	0%	\$0	\$0	\$0		\$0
	1140	Dewatering	\$0	0%	\$0	\$0	\$0		\$0
	1200	Site Improvements						\$5,619	
	1210	Earthwork	\$1,856	15%	\$2,134	3%	\$2,198		\$2,198
	1220	Drainage	\$370	25%	\$463	3%	\$476		\$476
	1230	Roads & Paving	\$1,551	20%	\$1,861	6%	\$1,973		\$1,973
	1240	Rail System	\$0	0%	\$0	0%	\$0		\$0
	1250	Waterway Improvements	\$376	15%	\$432	6%	\$458		\$458
	1260	Landscaping	\$52	10%	\$57	6%	\$61		\$61
	1270	Fencing And Gates	\$371	15%	\$427	6%	\$452		\$452
	1300	Utility Supply and Distribution Systems						\$3,783	
	1310	Central Heat Pump System	\$0	0%	\$0	0%	\$0		\$0
	1320	Central HVAC Chiller System	\$0	0%	\$0	0%	\$0		\$0
	1330	Water Supply And Treatment System	\$767	15%	\$882	6%	\$935		\$935
	1340	Sanitary Wastewater Collection And Treatment Sys	\$256	15%	\$294	6%	\$312		\$312
	1350	Natural Gas Distribution System	\$675	15%	\$776	6%	\$823		\$823
	1360	Yard Fire Protection System	\$937	15%	\$1,078	6%	\$1,142		\$1,142
	1370	Compressed Air System	\$468	15%	\$538	6%	\$570		\$570
	1380	Steam System	\$0	0%	\$0	0%	\$0		\$0
	1400	Yard Electrical System						\$62,115	
	1410	Electrical Equipment	\$50,956	15%	\$58,599	6%	\$62,115		\$62,115
	1420	Electrical Material (Included in 4110)	\$0	0%	\$0	0%	\$0		\$0

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor	Const. Cost	Design Estimate	Item Total	Subtotal	Total
			%	%		%			
2	1500	Other Electrical Systems							
	1510	Lighting Systems	\$71	20%	\$85	6%	\$90	\$1,268	
	1520	Communication Systems	\$209	20%	\$251	6%	\$266		
	1530	Security Systems	\$369	20%	\$443	6%	\$469		
	1540	Grounding	\$29	20%	\$35	6%	\$37		
	1550	Cathodic Protection	\$101	20%	\$121	6%	\$128		
	1560	Lightning Protection	\$101	20%	\$121	6%	\$128		
	1570	Freeze Protection	\$57	20%	\$68	6%	\$73		
	1580	Environmental Monitoring	\$24	20%	\$29	6%	\$31		
	1590	DC Power for Instrumentation	\$36	20%	\$43	6%	\$46		
1	2000	Buildings	\$103,058	24%	\$127,953	7,604	\$135,567		\$135,567
1	2100	Test Preparations/Control Building						\$69,504	
	2110	LSWT/...Prep/Control	\$33,767	25%	\$42,209	6%	\$44,741		
	2120	TSWT/...Prep/Control	\$18,689	25%	\$23,361	6%	\$24,763		
1	2200	Wind Tunnel Drive Buildings						\$8,692	
	2210	LSWT/TSWT Drive Building	\$6,998	15%	\$8,048	8%	\$8,692		
	2220	Not Used	\$0	0%	\$0	0%	\$0		
1	2300	Support Buildings						\$39,160	
	2310	Model Shop And Warehouse	\$19,557	25%	\$24,446	6%	\$25,913		
	2320	Support Shop Building(Included in 2110)	\$0	0%	\$0	0%	\$0		
	2330	Engineering Office	\$2,051	20%	\$2,461	8%	\$2,658		
1	2340	Guard House	\$205	10%	\$226	6%	\$239		
	2350	Outfitting	\$8,625	20%	\$10,350	0%	\$10,350		
1	2400	Utility Buildings						\$18,211	
	2410	WT Press/Vac Building	\$5,077	25%	\$6,346	8%	\$6,854		
	2420	Not Used	\$0	0%	\$0	0%	\$0		
	2430	Heat Pump System Equipment Building	\$0	0%	\$0	0%	\$0		
	2440	HVAC Chiller Building	\$0	0%	\$0	0%	\$0		
	2450	Utility Tunnels	\$7,881	30%	\$10,245	8%	\$11,065		
	2460	Other Minor Buildings	\$208	30%	\$270	8%	\$292		
	2470	Motor Pool Vehicles (Transferred to 2350)	\$0	0%	\$0	0%	\$0		
3	3000	Auxiliary Process Systems	\$148,947	24%	\$184,325	\$10,348	\$194,673		\$194,673
3	3100	Test Model And Cart Transport						\$6,698	
	3110	LSWT Shuttle Cart	\$2,600	30%	\$3,380	12%	\$3,786		
	3120	TSWT Shuttle Cart	\$2,000	30%	\$2,600	12%	\$2,912		
3	3200	Wind Tunnel Pressurization/Vacuum System						\$110,040	
	3210	Compressors, Driers, Pumps, Etc.	\$43,394	30%	\$56,412	3%	\$58,105		
	3220	Heaters And Coolers	\$915	20%	\$1,098	10%	\$1,208		
	3230	Drier System	\$8,753	20%	\$10,504	1%	\$10,609		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
*	3240	Filters	\$1,379	20%	\$1,655	1%	\$1,671		
*	3250	Distribution Piping	\$14,474	20%	\$17,369	10%	\$19,106		
*	3260	Storage Tanks	\$12,360	15%	\$14,214	8%	\$15,067		
*	3270	Muffler Towers	\$1,394	15%	\$1,603	8%	\$1,699		
*	3280	Vacuum System	\$2,209	10%	\$2,430	8%	\$2,576		
3	3400	Cooling System					\$20,218		
*	3410	Cooling Towers	\$8,652	20%	\$10,382	2%	\$10,590		
*	3420	Cw Circ Pumps & Motors	\$3,254	25%	\$4,068	2%	\$4,149		
*	3430	Miscellaneous Equipment	\$138	25%	\$173	8%	\$186		
*	3440	Distribution System Piping	\$4,084	20%	\$4,901	8%	\$5,293		
6	3500	Not Used							
3	3600	Miscellaneous Support Systems					\$42,089		
*	3610	Tunnel Cleaning System	\$3,600	30%	\$4,680	10%	\$5,148		
*	3620	Calibration System (High Pressure Air/Model Prop.)	\$26,866	25%	\$33,583	10%	\$36,941		
	3630	Compressor Blade Handling System(Transferred to	\$0	0%	\$0	0%	\$0		
3	3700	Scavenging And Fire Supression System					\$0		
	3710	Combustible Gas Scavenging System (Not used)	\$0	0%	\$0	0%	\$0		
	3720	Tunnel Fire Suppression System (Not used)	\$0	0%	\$0	0%	\$0		
2	3800	Aux. Electr Control Systems And Data Acquisition					\$4,262		
	3810	Electrical Equipment	\$3,496	15%	\$4,020	8%	\$4,262		
	3820	Electrical Bulks(Included in 3810)	\$0	0%	\$0	0%	\$0		
	3830	Control System (Transferred to 7710)	\$0	0%	\$0	0%	\$0		
	3840	Data Acquisition And Processing Systems (Transfer	\$0	0%	\$0	0%	\$0		
3	3900	Auxiliary Test And Validation					\$6,293		
	3910	Test And Validation	\$3,461	20%	\$4,154	1%	\$4,195		
	3920	Calibration	\$1,731	20%	\$2,077	1%	\$2,098		
	3A00	Productivity Provisions					\$5,075		
	3A10	Productivity Provisions	\$4,187	20%	\$5,024	1%	\$5,075		
4	4000	Low Speed Wind Tunnel	\$408,948	32%	\$537,867	\$33,075	\$570,942		\$570,942
4	4100	LSWT Enclosure					\$34,939		
*	4110	Foundation	\$10,235	20%	\$12,282	8%	\$13,265		
*	4120	Enclosure	\$15,317	20%	\$18,380	8%	\$19,851		
*	4130	Acoustic Insulation	\$399	20%	\$479	8%	\$508		
*	4140	Electrical Services	\$544	15%	\$626	8%	\$663		
*	4150	Mechanical Services	\$536	15%	\$616	8%	\$653		
4	4200	LSWT Pressure Shell					\$198,433		
	4210	LSWT Support Foundation( Incl. in 4110)	\$0	0%	\$0	0%	\$0		
*	4220	LSWT Support Structure	\$16,400	25%	\$20,500	3%	\$21,115		
*	4230	LSWT Pressure Shell	\$139,073	25%	\$173,841	2%	\$177,318		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
4	4300	LSWT Pressure Isolation System							
	4310	LSWT Isolation Valves	\$7,380	60%	\$11,808	15%	\$13,579	\$13,833	
	4320	LSWT Personnel Access (Not used)	\$0	0%	\$0	0%	\$0		
	4330	Hydraulic Power Unit	\$186	30%	\$242	5%	\$254		
	4340	Exhaust Silencer (Transferred to 3270)	\$0	0%	\$0	0%	\$0		
4	4400	LSWT Flow Internals						\$64,763	
	4410	Turning Vanes	\$9,861	30%	\$12,819	10%	\$14,101		
	4420	Honeycomb	\$3,347	40%	\$4,686	10%	\$5,154		
	4430	Screens	\$3,116	40%	\$4,362	10%	\$4,799		
	4440	Internal Heat Exchanger	\$9,685	20%	\$11,622	5%	\$12,203		
	4450	Settling Chamber Liner	\$15,687	30%	\$20,393	10%	\$22,432		
	4460	Plenum Evacuation System (Not used)	\$0	0%	\$0	0%	\$0		
	4470	Gas Manifolding(Not used)	\$0	0%	\$0	0%	\$0		
	4480	High Speed Diffuser	\$2,220	30%	\$2,886	10%	\$3,175		
	4490	Acoustic Treatment for nacelles	\$2,027	30%	\$2,635	10%	\$2,899		
	44A0	Compressor FOD Protection (Not Used)	\$0	0%	\$0	0%	\$0		
	44B0	Acoustic Baffles (Not used)	\$0	0%	\$0	0%	\$0		
	44C0	Tunnel Cleaning System(Transferred to 3610)	\$0	0%	\$0	0%	\$0		
4	4500	Test Plenum						\$120,555	
	4510	Subsonic Nozzle(Transferred to 4450)	\$0	0%	\$0	0%	\$0		
	4520	Flutter Test Section (Not In Concept )	\$0	0%	\$0	0%	\$0		
	4530	Open Jet Test Section	\$9,306	50%	\$13,959	15%	\$16,053		
	4540	Moveable Plenum	\$11,841	40%	\$16,577	10%	\$18,235		
	4550	Not used	\$0	0%	\$0	0%	\$0		
	4560	Observation System	\$385	40%	\$539	10%	\$593		
	4570	Test Section Carts	\$40,677	60%	\$65,083	15%	\$74,846		
	4580	Preparation Hail Shuttle Cart	\$0	0%	\$0	0%	\$0		
	4590	Anechoic Chamber	\$7,572	30%	\$9,844	10%	\$10,828		
4	4600	Test Support Equipment						\$21,839	
	4610	Vertical Strut Assembly (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
	4620	Floor Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
	4630	Half Model Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
	4640	Moving Ground Plane (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
	4650	Elevated Ground Plane	\$1,788	50%	\$2,682	10%	\$2,950		
	4660	Inverted Ground Plane	\$1,788	50%	\$2,682	10%	\$2,950		
	4670	Sting (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
	4680	External Balance	\$9,900	40%	\$13,860	15%	\$15,939		
6	4700	Compressor and Drive System						\$55,790	
	4710	Rotor Hub/Blades	\$9,750	30%	\$12,675	3%	\$13,055		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
*	4720	Shaft/Bearings/Clutch	\$2,960	25%	\$3,700	2%	\$3,774		
*	4730	Nacelles/Fairings and Supports	\$2,200	30%	\$2,860	9%	\$3,003		
*	4740	Gearbox	\$0	0%	\$0	0%	\$0		
*	4750	Lubrication and Cooling System	\$200	20%	\$240	5%	\$252		
*	4760	Motor	\$4,500	20%	\$5,400	1%	\$5,454		
*	4770	Motor Drive Controls	\$13,500	20%	\$16,200	2%	\$16,524		
*	4780	Compressor Pressure Shell/Stators/GV/OGV	\$8,800	50%	\$13,200	4%	\$13,728		
6	4800	Electrical, Controls System and Data Acquisition						\$0	
	4810	Electrical Equipment (Transferred to 1410)	\$0	0%	\$0	0%	\$0		
	4820	Electrical Materials (Transferred to 1420)	\$0	0%	\$0	0%	\$0		
	4830	Control and Instrumentation (Transferred to 7720)							
	4840	Data Acquisition and Processing Systems (Transferred to 7220)							
4	4900	Test & Validation						\$40,526	
	4910	Test and Validation	\$23,884	20%	\$28,661	1%	\$28,947		
	4920	Calibration	\$9,554	20%	\$11,464	1%	\$11,579		
4A00	Productivity Provisions							\$20,263	
	4A10	Productivity Provisions	\$14,330	40%	\$20,063	1%	\$20,263		
5	5000	Transonic Wind Tunnel (TSWT)	\$352,514	30%	\$460,019	\$29,708	\$489,728		\$489,728
5	5100	TSWT Enclosure						\$25,760	
*	5110	Foundation	\$7,627	20%	\$9,152	8%	\$9,885		
*	5120	Enclosure	\$11,400	20%	\$13,680	8%	\$14,774		
*	5130	Acoustic Insulation	\$284	20%	\$341	8%	\$361		
*	5140	Electrical Services	\$306	15%	\$352	8%	\$373		
*	5150	Mechanical Services	\$301	15%	\$346	8%	\$367		
5	5200	Pressure Vessels						\$62,843	
	5210	Foundations	\$0	0%	\$0	0%	\$0		
*	5220	Shell Support System	\$4,700	25%	\$5,875	9%	\$6,169		
*	5230	TSWT Pressure Shell	\$43,180	25%	\$53,975	9%	\$56,674		
5	5300	Pressure Isolation System						\$9,431	
*	5310	TSWT Isolation Valves	\$4,000	100%	\$8,000	15%	\$9,200		
*	5320	TSWT Personnel Access	\$0	0%	\$0	0%	\$0		
	5330	Hydraulic Power Unit	\$150	40%	\$210	10%	\$231		
5	5400	TSWT Flow Internals						\$80,267	
	5410	Tuning Vanes	\$4,275	20%	\$5,130	10%	\$5,643		
	5420	Honeycomb	\$1,019	30%	\$1,325	10%	\$1,457		
	5430	Screens	\$1,400	30%	\$1,820	10%	\$2,002		
*	5440	Internal Heat Exchanger	\$8,056	30%	\$10,473	10%	\$11,520		
	5450	Settling Chamber Liner	\$2,040	40%	\$2,856	10%	\$3,142		
*	5460	Plenum Evacuation System	\$23,240	20%	\$27,888	5%	\$29,282		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	5470	Acoustic Baffles	\$600	20%	\$720	15%	\$828		
=	5480	Flexible Nozzle	\$9,500	40%	\$13,300	15%	\$15,295		
	5490	Compressor FOD Protection	\$3,400	20%	\$4,080	15%	\$4,692		
	54A0	Choke System	\$3,100	30%	\$4,030	20%	\$4,836		
=	54B0	High Speed Diffuser Liner	\$975	40%	\$1,365	15%	\$1,570		
	54C0	Ejection System	\$0	30%	\$0	12%	\$0		
5	5500	TSWT Test Plenum	\$60,500	40%	\$84,700	12%	\$94,864		
	5510	Test Section	\$6,000	40%	\$8,400	15%	\$9,660		
*	5520	Moveable Plenum	\$200	40%	\$280	15%	\$322		
	5530	Observation System	\$0	0%	\$0	0%	\$0		
	5540	Preparation Hall Shuttle Cart	\$0	0%	\$0	0%	\$0		
5	5600	TSWT Test Support Equipment	\$0	0%	\$0	0%	\$0		
	5610	Model Support (Incl. in 5510)	\$0	0%	\$0	0%	\$0		
	5620	Floor Mounts (Interface only)	\$0	0%	\$0	0%	\$0		
	5630	Half Model Mounts(Interface only)	\$0	0%	\$0	0%	\$0		
	5640	Slings and Booms(Incl. in 7440)	\$0	0%	\$0	0%	\$0		
	5650	External Balance	\$4,400	40%	\$6,160	15%	\$7,084		
	5660	Other Test Support Equipment(Incl. in 7740)	\$0	0%	\$0	0%	\$0		
6	5700	TSWT Compressor Drive System	\$27,020	40%	\$37,828	2%	\$38,585		
	5710	Rotor Hub/Blades	\$7,660	35%	\$10,341	2%	\$10,548		
	5720	Shaft/Bearings/Clutch	\$6,900	45%	\$10,005	5%	\$10,505		
*	5740	Nacelles/Fairings and Supports	\$12,660	45%	\$18,357	4%	\$19,091		
	5750	Compressor Pressure Shell/Stators/IGV/OGV	\$340	20%	\$408	5%	\$428		
	5760	Lubrication & Cooling System	\$14,750	20%	\$17,700	1%	\$17,877		
	5770	Motors	\$44,250	20%	\$53,100	2%	\$54,162		
	5780	Gearbox Included With 3530	\$0	0%	\$0	0%	\$0		
6	5800	TSWT Elec. Control Systems and Data Acquisition	\$0	0%	\$0	0%	\$0		
	5810	Electrical Equipment	\$0	0%	\$0	0%	\$0		
	5820	Electrical Materials	\$0	0%	\$0	0%	\$0		
	5830	Control Systems (Transferred to 7730)							
	5840	Data Acquisition and Data Processing Systems (Transferred to 7230)							
5	5900	TSWT Test and Validation	\$20,610	20%	\$24,732	1%	\$24,979		
	5910	Test and Validation	\$8,244	20%	\$9,893	1%	\$9,992		
	5920	Calibration							
	5A00	Productivity Items							
	5A10	Productivity Items	\$9,427	40%	\$13,198	1%	\$13,330		
7	7000	Operations (LSWT & TSWT)	\$106,479	23%	\$131,073	\$17,145	\$148,218		
	7100	Calibration						\$32,913	\$148,218

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	7110	Auxiliary Process System Calibration	\$0	0%	\$0	0%	\$0		
	7120	Airflow Calibration Lab	\$2,628	50%	\$3,942	12%	\$4,415		
	7130	Balance Calibration Lab	\$10,500	20%	\$12,600	20%	\$15,120		
	7140	Structural Calibration Lab	\$187	10%	\$206	5%	\$216		
	7150	Instrument Calibration Lab	\$2,923	10%	\$3,215	10%	\$3,537		
	7160	Calibration Hardware - LSWT	\$304	20%	\$365	25%	\$456		
	7170	Calibration Hardware - TSWT	\$304	20%	\$365	25%	\$456		
	7180	Calibration Model	\$193	30%	\$251	25%	\$314		
	7190	External Balance Calibrator	\$5,000	40%	\$7,000	20%	\$8,400		
7	7200	Data Acquisition System						\$39,914	
	7210	Data Acquisition System - Aux. Systems (from 3840)	\$0	0%	\$0	0%	\$0		
	7220	Data Acquisition System - LSWT (from 4840)	\$15,891	20%	\$19,069	5%	\$20,023		
	7230	Data Acquisition System - TSWT (from 5840)	\$15,787	20%	\$18,944	5%	\$19,892		
7	7300	Wind Tunnel Balance						\$6,150	
	7310	Balance (Internal) LSWT	\$1,800	40%	\$2,520	25%	\$3,150		
	7320	Balance (Internal) TSWT	\$2,000	20%	\$2,400	25%	\$3,000		
7	7400	Models and Models Supports						\$5,229	
	7410	Model Handling Equipment (LSWT)(From 3120)	\$256	20%	\$307	6%	\$326		
	7420	Model Handling Equipment (TSWT)	\$256	20%	\$307	6%	\$326		
	7430	Stings and Struts (LSWT)	\$1,417	30%	\$1,842	16%	\$2,137		
	7440	Stings and Struts TSWT	\$1,443	20%	\$1,732	16%	\$2,009		
	7450	Acoustic Traverse Rake	\$300	20%	\$360	20%	\$432		
7	7500	Instrumentation						\$40,686	
	7510	Test (LSWT)	\$13,212	20%	\$15,854	12%	\$17,757		
	7520	Test (TSWT)	\$10,060	20%	\$12,072	12%	\$13,521		
	7530	Calibration (LSWT)	\$159	20%	\$191	18%	\$225		
	7540	Calibration (TSWT)	\$159	20%	\$191	18%	\$225		
	7550	Acoustics (LSWT)	\$370	20%	\$444	10%	\$488		
	7560	Acoustics (TSWT)	\$0	0%	\$0	0%	\$0		
	7570	Processes (LSWT)	\$1,917	20%	\$2,300	12%	\$2,576		
	7580	Process (TSWT)	\$2,332	20%	\$2,798	12%	\$3,134		
	7590	Hardware Integ. (LSWT)	\$622	15%	\$715	15%	\$823		
	75A0	Hardware Integ. (TSWT)	\$622	15%	\$715	15%	\$823		
	75B0	Aux. process Instr. LSWT & BWT	\$714	30%	\$928	20%	\$1,114		
7	7600	Operations Integration Analysis Plan (Incl. in 8350)						\$0	
	7610	Productivity (LSWT)	\$0	0%	\$0	0%	\$0		
	7620	Productivity (TSWT)	\$0	0%	\$0	0%	\$0		
	7630	Maintenance (LSWT)	\$0	0%	\$0	0%	\$0		
	7640	Maintenance (TSWT)	\$0	0%	\$0	0%	\$0		

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor	Const. Cost	Design Estimate	Item Total	Subtotal	Total
				%		%			
	7650	Maintenance - Aux. Syst.		0%	\$0	0%	\$0		
	7660	Instr. Acc. Assessment LSWT & TSWT	\$0	0%	\$0	0%	\$0		
7	7700	Controls						\$23,325	
	7710	Controls - Auxiliary Process Systems (from 3830)	\$1,480	15%	\$1,702	20%	\$2,042		
	7720	Controls - LSWT (from 4830)	\$6,595	30%	\$8,574	20%	\$10,288		
	7730	Controls - TSWT (from 5830)	\$7,048	30%	\$9,162	20%	\$10,995		
		<b>Subtotal</b>	<b>\$1,179,624</b>	<b>28%</b>	<b>\$1,510,054</b>	<b>\$101,931</b>	<b>\$1,611,985</b>	<b>\$1,611,985</b>	<b>\$1,611,985</b>
8	8000	Management and Support				7%			
8	8100	Program Management	\$198,671	2%	\$201,930	\$0	\$201,930	\$133,501	\$201,930
	8110	Prime Contractor's Program Office	\$74,750	0%	\$74,750	0%	\$74,750		
	8120	Operator Training	\$21,000	0%	\$21,000	0%	\$21,000		
	8130	Maintenance and Operation Support	\$37,751	0%	\$37,751	0%	\$37,751		
	8140	Not used	\$0	0%	\$0	0%	\$0		
8	8200	Quality Assurance						\$0	
	8210	Quality Assurance	\$0	0%	\$0	0%	\$0		
8	8300	Systems Engineering and Integration						\$0	
	8310	System Engineering and Intergration	\$0	0%	\$0	0%	\$0		
	8320	General Engineering	\$0	0%	\$0	0%	\$0		
	8330	Performance/System Specifications	\$0	0%	\$0	0%	\$0		
	8340	Construction	\$0	0%	\$0	0%	\$0		
8	8400	Procurement						\$0	
	8410	Procurement	\$0	0%	\$0	0%	\$0		
8	8500	Construction Management						\$0	
	8510	Not used	\$0	0%	\$0	0%	\$0		
	8520	Not used	\$0	0%	\$0	0%	\$0		
	8530	Not used	\$0	0%	\$0	0%	\$0		
	8540	Not used	\$0	0%	\$0	0%	\$0		
	8600	Site and Permits							
	8700	Field Indirect	\$65,170	9%	\$68,429	0%	\$68,429	\$68,429	
		<b>Total</b>	<b>\$1,378,295</b>	<b>24%</b>	<b>\$1,711,984</b>	<b>\$101,931</b>	<b>\$1,813,915</b>	<b>\$1,813,915</b>	<b>\$1,813,915</b>
		<b>Project Assessment</b>				6%			
		Profit				10%	\$171,198	\$1,883,182	\$1,511,409
		Bond				1%	\$18,832	\$1,902,014	
		Cost Adjustment (7 yr. @ 3.5%)				27%	\$513,544	\$2,415,558	
		Construction Cost Estimate						\$2,415,558	

Work Pkg.	WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
		Contingency				10%	\$241,556	\$2,657,114	
		SIES				8%	\$212,569	\$2,869,683	
		<b>Total Construction Budget Estimate</b>						<b>\$2,869,683</b>	
		PER					\$46,000	\$2,915,683	
		Government Project Management				10%	\$151,005	\$3,066,688	
		Studies					\$38,523	\$3,105,211	
		Design(Including Design Management)					\$118,181	\$3,223,393	
		Real Estate					\$0	\$3,223,393	
		Other Burden Expense					\$0	\$3,223,393	
		<b>Project Total</b>					<b>\$3,223,393</b>		<b>\$3,223,393</b>

# National Wind Tunnel Complex

## FSO Concept

### Draft Facility Cost Estimate

(Dollars in Thousand)

## Concept D-5

### FSO Government Model

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
1000	Site And Infrastructure	\$58,270	15%	\$67,188	\$3,953	\$71,141		\$71,141
1100	Site Preparation						\$72	
1110	Investigation (Design Process Only)	\$0	0%	\$0	\$0	\$0		
1120	Clearing And Grubbing	\$46	50%	\$69	5%	\$72		
1130	Demolition	\$0	0%	\$0	\$0	\$0		
1140	Dewatering	\$0	0%	\$0	\$0	\$0		
1200	Site Improvements						\$5,619	
1210	Earthwork	\$1,856	15%	\$2,134	3%	\$2,198		
1220	Drainage	\$370	25%	\$463	3%	\$476		
1230	Roads & Paving	\$1,551	20%	\$1,861	6%	\$1,973		
1240	Rail System	\$0	0%	\$0	0%	\$0		
1250	Waterway Improvements	\$376	15%	\$432	6%	\$458		
1260	Landscaping	\$52	10%	\$57	6%	\$61		
1270	Fencing And Gates	\$371	15%	\$427	6%	\$452		
1300	Utility Supply and Distribution Systems						\$3,783	
1310	Central Heat Pump System	\$0	0%	\$0	0%	\$0		
1320	Central HVAC Chiller System	\$0	0%	\$0	0%	\$0		
1330	Water Supply And Treatment System	\$767	15%	\$882	6%	\$935		
1340	Sanitary Wastewater Collection And Treatment Sys	\$256	15%	\$294	6%	\$312		
1350	Natural Gas Distribution System	\$675	15%	\$776	6%	\$823		
1360	Yard Fire Protection System	\$937	15%	\$1,078	6%	\$1,142		
1370	Compressed Air System	\$468	15%	\$538	6%	\$570		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
1380	Steam System							
1400	Yard Electrical System	\$0	0%	\$0	0%	\$0		
1410	Electrical Equipment	\$49,548	15%	\$56,980	6%	\$60,399	\$60,399	
1420	Electrical Material (Included in 4110)	\$0	0%	\$0	0%	\$0		
1500	Other Electrical Systems						\$1,268	
1510	Lighting Systems	\$71	20%	\$85	6%	\$90		
1520	Communication Systems	\$209	20%	\$251	6%	\$266		
1530	Security Systems	\$369	20%	\$443	6%	\$469		
1540	Grounding	\$29	20%	\$35	6%	\$37		
1550	Cathodic Protection	\$101	20%	\$121	6%	\$128		
1560	Lighting Protection	\$101	20%	\$121	6%	\$128		
1570	Freeze Protection	\$57	20%	\$68	6%	\$73		
1580	Environmental Monitoring	\$24	20%	\$29	6%	\$31		
1590	DC Power for Instrumentation	\$36	20%	\$43	6%	\$46		
2000	Buildings	\$103,074	20%	\$124,107	\$7,366	\$131,472		\$131,472
2100	Test Preparations/Control Building						\$66,835	
2110	LSWT/...Prep/Control	\$33,890	20%	\$40,668	6%	\$43,108		
2120	TSWT/...Prep/Control	\$18,653	20%	\$22,384	6%	\$23,727		
2200	Wind Tunnel Drive Buildings						\$8,692	
2210	LSWT/TSWT Drive Building	\$6,998	15%	\$8,048	8%	\$8,692		
2220	Not Used	\$0	0%	\$0	0%	\$0		
2300	Support Buildings						\$38,124	
2310	Model Shop And Warehouse	\$19,557	20%	\$23,468	6%	\$24,877		
2320	Support Shop Building(Included in 2110)	\$0	0%	\$0	0%	\$0		
2330	Engineering Office	\$2,051	20%	\$2,461	8%	\$2,658		
2340	Guard House	\$205	10%	\$226	6%	\$239		
2350	Outfitting	\$8,625	20%	\$10,350	0%	\$10,350		
2400	Utility Buildings						\$17,822	
2410	WT Press/Vac Building	\$5,006	20%	\$6,007	8%	\$6,488		
2420	Not Used	\$0	0%	\$0	0%	\$0		
2430	Heat Pump System Equipment Building	\$0	0%	\$0	0%	\$0		
2440	HVAC Chiller Building	\$0	0%	\$0	0%	\$0		
2450	Utility Tunnels	\$7,881	30%	\$10,245	8%	\$11,065		
2460	Other Minor Buildings	\$208	20%	\$250	8%	\$270		
2470	Motor Pool Vehicles (Transferred to 2350)	\$0	0%	\$0	0%	\$0		
3000	Auxiliary Process Systems	\$114,408	20%	\$137,429	\$8,232	\$145,661		\$145,661
3100	Test Model And Cart Transport						\$6,698	
3110	LSWT Shuttle Cart	\$2,600	30%	\$3,380	12%	\$3,786		
3120	TSWT Shuttle Cart	\$2,000	30%	\$2,600	12%	\$2,912		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
3200	Wind Tunnel Pressurization/Vacuum System							
3210	Compressors, Driers, Pumps, Etc.	\$28,931	20%	\$34,717	3%	\$35,759	\$82,850	
3220	Heaters And Coolers	\$915	20%	\$1,098	5%	\$1,153		
3230	Drier System	\$5,821	20%	\$6,985	1%	\$7,055		
3240	Filters	\$962	20%	\$1,154	1%	\$1,166		
3250	Distribution Piping	\$14,474	20%	\$17,369	10%	\$19,106		
3260	Storage Tanks	\$11,761	15%	\$13,525	6%	\$14,337		
3270	Muffler Towers	\$1,394	15%	\$1,603	6%	\$1,699		
3280	Vacuum System	\$2,209	10%	\$2,430	6%	\$2,576		
3400	Cooling System						\$15,114	
3410	Cooling Towers	\$4,854	20%	\$5,825	1%	\$5,883		
3420	Cw Circ Pumps & Motors	\$3,581	20%	\$4,297	1%	\$4,340		
3430	Miscellaneous Equipment	\$138	20%	\$166	8%	\$179		
3440	Distribution System Piping	\$3,636	20%	\$4,363	8%	\$4,712		
3500	Not Used							
3600	Miscellaneous Support Systems							
3610	Tunnel Cleaning System	\$3,600	30%	\$4,680	10%	\$5,148	\$30,592	
3620	Calibration System (High Pressure Air/Model Prop.)	\$18,505	25%	\$23,131	10%	\$25,444		
3630	Compressor Blade Handling System(Transferred to	\$0	0%	\$0	0%	\$0		
3700	Scavenging And Fire Suppression System							
3710	Combustible Gas Scavenging System (Not used)	\$0	0%	\$0	0%	\$0	\$0	
3720	Tunnel Fire Suppression System (Not used)	\$0	0%	\$0	0%	\$0		
3800	Aux. Electr Control Systems And Data Acquisition						\$4,262	
3810	Electrical Equipment	\$3,496	15%	\$4,020	6%	\$4,262		
3820	Electrical Bulks(Included in 3810)	\$0	0%	\$0	0%	\$0		
3830	Control System (Transferred to 7710)	\$0	0%	\$0	0%	\$0		
3840	Data Acquisition And Processing Systems (Transfer	\$0	0%	\$0	0%	\$0		
3900	Auxiliary Test And Validation							
3910	Test And Validation	\$1,510	10%	\$1,661	1%	\$1,678	\$2,516	
3920	Calibration	\$755	10%	\$831	1%	\$839		
3A00	Productivity Provisions						\$3,629	
3A10	Productivity Provisions	\$3,266	10%	\$3,593	1%	\$3,629		
4000	Low Speed Wind Tunnel	\$386,622	32%	\$509,999	\$28,359	\$538,358		\$538,358
4100	LSWT Enclosure							
4110	Foundation	\$14,359	20%	\$17,231	8%	\$18,609	\$36,811	
4120	Enclosure	\$12,478	20%	\$14,974	8%	\$16,171		
4130	Acoustic Insulation	\$561	20%	\$673	6%	\$714		
4140	Electrical Services	\$544	15%	\$626	6%	\$663		
4150	Mechanical Services	\$536	15%	\$616	6%	\$653		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
4200	LSWT Pressure Shell						\$198,433	
4210	LSWT Support Foundation( Incl. in 4110)	\$0	0%	\$0	0%	\$0		
4220	LSWT Support Structure	\$16,400	25%	\$20,500	3%	\$21,115		
4230	LSWT Pressure Shell	\$139,073	25%	\$173,841	2%	\$177,318		
4300	LSWT Pressure Isolation System						\$13,243	
4310	LSWT Isolation Valves	\$7,380	60%	\$11,808	10%	\$12,989		
4320	LSWT Personnel Access (Not used)	\$0	0%	\$0	0%	\$0		
4330	Hydraulic Power Unit	\$186	30%	\$242	5%	\$254		
4340	Exhaust Silencer (Transferred to 3270)	\$0	0%	\$0	0%	\$0		
4400	LSWT Flow Internals						\$62,892	
4410	Turning Vanes	\$8,886	30%	\$11,552	10%	\$12,707		
4420	Honeycomb	\$3,347	30%	\$4,351	10%	\$4,786		
4430	Screens	\$3,116	30%	\$4,051	10%	\$4,456		
4440	Internal Heat Exchanger	\$9,685	20%	\$11,622	5%	\$12,203		
4450	Settling Chamber Liner	\$15,687	30%	\$20,393	10%	\$22,432		
4460	Plenum Evacuation System (Not used)	\$0	0%	\$0	0%	\$0		
4470	Gas Manifolding(Not used)	\$0	0%	\$0	0%	\$0		
4480	High Speed Diffuser	\$2,220	30%	\$2,886	10%	\$3,175		
4490	Acoustic Treatment for nacelles	\$2,027	30%	\$2,635	10%	\$2,899		
44A0	Compressor FOD Protection	\$164	30%	\$213	10%	\$235		
44B0	Acoustic Baffles (Not used)	\$0	0%	\$0	0%	\$0		
44C0	Tunnel Cleaning System(Transferred to 3610)	\$0	0%	\$0	0%	\$0		
4500	Test Plenum						\$117,712	
4510	Subsonic Nozzle(Transferred to 4450)	\$0	0%	\$0	0%	\$0		
4520	Flutter Test Section (Not in Concept )	\$0	0%	\$0	0%	\$0		
4530	Open Jet Test Section	\$9,306	60%	\$14,890	15%	\$17,123		
4540	Moveable Plenum	\$11,841	40%	\$16,577	8%	\$17,904		
4550	Not used	\$0	0%	\$0	0%	\$0		
4560	Observation System	\$385	40%	\$539	10%	\$593		
4570	Test Section Carts	\$40,677	60%	\$65,083	12%	\$72,893		
4580	Preparation Hall Shuttle Cart	\$0	0%	\$0	0%	\$0		
4590	Anechoic Chamber	\$6,433	30%	\$8,363	10%	\$9,199		
4600	Test Support Equipment						\$20,315	
4610	Vertical Strut Assembly (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
4620	Floor Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4630	Half Model Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4640	Moving Ground Plane (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
4650	Elevated Ground Plane	\$1,788	50%	\$2,682	10%	\$2,950		
4660	Inverted Ground Plane	\$1,788	50%	\$2,682	10%	\$2,950		

WBS No.	Item and Description	Engineering Estimate	Risk Factor	Const. Cost	Design Estimate	Item Total	Subtotal	Total
		%	%	%	%			
4670	Sling (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4680	External Balance	\$9,900	40%	\$13,860	4%	\$14,414		
4700	Compressor and Drive System						\$55,790	
4710	Rotor Hub/Blades	\$9,750	30%	\$12,675	3%	\$13,055		
4720	Shaft/Bearings/Clutch	\$2,960	25%	\$3,700	2%	\$3,774		
4730	Nacelles/Fairings and Supports	\$2,200	30%	\$2,860	5%	\$3,003		
4740	Gearbox	\$0	0%	\$0	0%	\$0		
4750	Lubrication and Cooling System	\$200	20%	\$240	5%	\$252		
4760	Motor	\$4,500	20%	\$5,400	1%	\$5,454		
4770	Motor Drive Controls	\$13,500	20%	\$16,200	2%	\$16,524		
4780	Compressor Pressure Shell/Stators/GV/OGV	\$8,800	50%	\$13,200	4%	\$13,728		
4800	Electrical, Controls System and Data Acquisition						\$0	
4810	Electrical Equipment (Transferred to 1410)	\$0	0%	\$0	0%	\$0		
4820	Electrical Materials (Transferred to 1420)	\$0	0%	\$0	0%	\$0		
4830	Control and Instrumentation (Transferred to 7720)							
4840	Data Acquisition and Processing Systems (Transferred to 7720)							
4900	Test & Validation							
4910	Test and Validation	\$7,960	10%	\$8,756	1%	\$8,844	\$12,921	
4920	Calibration	\$3,670	10%	\$4,037	1%	\$4,077		
4A00	Productivity Provisions						\$20,241	
4A10	Productivity Provisions	\$14,315	40%	\$20,041	1%	\$20,241		
5000	Transonic Wind Tunnel (TSWT)	\$320,997	29%	\$415,530	\$23,149	\$438,679		\$438,679
5100	TSWT Enclosure						\$21,595	
5110	Foundation	\$8,326	20%	\$9,991	8%	\$10,790		
5120	Enclosure	\$7,487	20%	\$8,984	8%	\$9,703		
5130	Acoustic Insulation	\$284	20%	\$341	6%	\$361		
5140	Electrical Services	\$306	15%	\$352	8%	\$373		
5150	Mechanical Services	\$301	15%	\$346	8%	\$367		
5200	Pressure Vessels						\$59,710	
5210	Foundations	\$0	0%	\$0	0%	\$0		
5220	Shell Support System	\$4,700	25%	\$5,875	5%	\$6,169		
5230	TSWT Pressure Shell	\$40,793	25%	\$50,991	5%	\$53,541		
5300	Pressure Isolation System						\$8,442	
5310	TSWT Isolation Valves	\$3,570	100%	\$7,140	15%	\$8,211		
5320	TSWT Personnel Access	\$0	0%	\$0	0%	\$0		
5330	Hydraulic Power Unit	\$150	40%	\$210	10%	\$231		
5400	TSWT Flow Internals						\$85,304	
5410	Turning Vanes	\$4,275	20%	\$5,130	10%	\$5,643		
5420	Honeycomb	\$1,019	30%	\$1,325	10%	\$1,457		

WBS No.	Item and Description	Engineering Estimate	Risk Factor	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
			%		%			
5430	Screens							
5440	Internal Heat Exchanger	\$1,400	30%	\$1,820	10%	\$2,002		
5450	Settling Chamber Liner	\$8,056	30%	\$10,473	10%	\$11,520		
5460	Plenum Evacuation System	\$2,040	40%	\$2,856	10%	\$3,142		
5470	Acoustic Baffles	\$23,240	20%	\$27,888	5%	\$29,282		
5480	Flexible Nozzle	\$600	20%	\$720	15%	\$828		
5490	Compressor FOD Protection	\$13,600	30%	\$17,680	15%	\$20,332		
54A0	Choke System	\$3,400	20%	\$4,080	15%	\$4,692		
54B0	High Speed Diffuser Liner	\$3,100	30%	\$4,030	20%	\$4,836		
54C0	Ejection System	\$975	40%	\$1,365	15%	\$1,570		
5500	TSWT Test Plenum	\$0	30%	\$0	12%	\$0		
5510	Test Section						\$79,595	
5520	Moveable Plenum	\$47,430	40%	\$66,402	7%	\$71,050		
5530	Observation System	\$5,500	30%	\$7,150	15%	\$8,223		
5540	Preparation Hall Shuttle Cart	\$200	40%	\$280	15%	\$322		
5600	TSWT Test Support Equipment	\$0	0%	\$0	0%	\$0		
5610	Model Support (Incl. In 5510)						\$6,406	
5620	Floor Mounts (Interface only)	\$0	0%	\$0	0%	\$0		
5630	Half Model Mounts(Interface only)	\$0	0%	\$0	0%	\$0		
5640	Sitings and Booms(Incl. In 7440)	\$0	0%	\$0	0%	\$0		
5650	External Balance	\$4,400	40%	\$6,160	4%	\$6,406		
5660	Other Test Support Equipment(Incl. In 7740)	\$0	0%	\$0	0%	\$0		
5700	TSWT Compressor Drive System						\$150,176	
5710	Rotor Hub/Blades	\$27,020	40%	\$37,828	2%	\$38,585		
5720	Shaft/Bearings/Clutch	\$7,660	35%	\$10,341	2%	\$10,548		
5730	Nacelles/Fairings and Supports	\$6,900	40%	\$9,660	5%	\$10,143		
5740	Compressor Pressure Shell/Stators/IGV/OGV	\$12,660	40%	\$17,724	4%	\$18,433		
5750	Lubrication & Cooling System	\$340	20%	\$408	5%	\$428		
5760	Motors	\$14,750	20%	\$17,700	1%	\$17,877		
5770	Motor Controls	\$44,250	20%	\$53,100	2%	\$54,162		
5780	Gearbox Included With 3530	\$0	0%	\$0	0%	\$0		
5800	TSWT Elec. Control Systems and Data Acquisition						\$0	
5810	Electrical Equipment	\$0	0%	\$0	0%	\$0		
5820	Electrical Materials	\$0	0%	\$0	0%	\$0		
5830	Control Systems (Transferred to 7730)							
5840	Data Acquisition and Data Processing Systems (Transferred to 7230)							
5900	TSWT Test and Validation	\$9,085	10%	\$9,994	1%	\$10,093	\$14,780	
5910	Test and Validation							
5920	Calibration	\$4,218	10%	\$4,640	1%	\$4,686		

WBS No.	Item and Description	Engineering Estimate	Risk Factor	Const. Cost	Design Estimate	Item Total	Subtotal	Total
			%		%			
5A00	Productivity Items							
5A10	Productivity Items							
7000	Operations (LSWT & TSWT)	\$8,962	40%	\$12,547	1%	\$12,672	\$12,672	
7100	Calibration	\$89,056	23%	\$109,310	\$13,491	\$122,800	\$122,800	\$122,800
7110	Auxiliary Process System Calibration	\$0	0%	\$0	0%	\$0	\$25,834	
7120	Airflow Calibration Lab	\$2,785	50%	\$4,178	12%	\$4,679		
7130	Balance Calibration Lab	\$11,130	20%	\$13,356	20%	\$16,027		
7140	Structural Calibration Lab	\$198	10%	\$218	5%	\$229		
7150	Instrument Calibration Lab	\$2,977	10%	\$3,275	10%	\$3,602		
7160	Calibration Hardware - LSWT	\$322	20%	\$386	25%	\$483		
7170	Calibration Hardware - TSWT	\$322	20%	\$386	25%	\$483		
7180	Calibration Model	\$204	30%	\$265	25%	\$332		
7190	External Balance Calibrator	\$0	40%	\$0	20%	\$0		
7200	Data Acquisition System						\$28,659	
7210	Data Acquisition System - Aux. Systems (from 3840)	\$0	0%	\$0	0%	\$0		
7220	Data Acquisition System - LSWT (from 4840)	\$12,849	20%	\$15,419	5%	\$16,190		
7230	Data Acquisition System - TSWT (from 5840)	\$9,896	20%	\$11,875	5%	\$12,469		
7300	Wind Tunnel Balance						\$6,519	
7310	Balance (Internal) LSWT	\$1,908	40%	\$2,671	25%	\$3,339		
7320	Balance (Internal) TSWT	\$2,120	20%	\$2,544	25%	\$3,180		
7400	Models and Models Supports						\$5,083	
7410	Model Handling Equipment (LSWT)(From 3120)	\$271	20%	\$325	6%	\$345		
7420	Model Handling Equipment (TSWT)	\$271	20%	\$325	6%	\$345		
7430	Stings and Struts (LSWT)	\$1,502	30%	\$1,953	16%	\$2,265		
7440	Stings and Struts TSWT	\$1,529	20%	\$1,835	16%	\$2,128		
7450	Acoustic Traverse Rake(Included in 4530)	\$0	0%	\$0	0%	\$0		
7500	Instrumentation						\$32,253	
7510	Test (LSWT)	\$10,403	20%	\$12,484	6%	\$13,233		
7520	Test (TSWT)	\$7,719	20%	\$9,263	6%	\$9,819		
7530	Calibration (LSWT)	\$162	20%	\$194	18%	\$229		
7540	Calibration (TSWT)	\$162	20%	\$194	18%	\$229		
7550	Acoustics (LSWT)	\$392	20%	\$470	10%	\$517		
7560	Acoustics (TSWT)	\$0	0%	\$0	0%	\$0		
7570	Processes (LSWT)	\$2,173	20%	\$2,608	12%	\$2,921		
7580	Process (TSWT)	\$2,218	20%	\$2,662	12%	\$2,981		
7590	Hardware Integ. (LSWT)	\$479	15%	\$551	8%	\$595		
75A0	Hardware Integ. (TSWT)	\$479	15%	\$551	8%	\$595		
75B0	Aux. process Instr. LSWT & BWT	\$727	30%	\$945	20%	\$1,134		
7600	Operations Integration Analysis Plan (Incl. in 8350)						\$0	

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
7610	Productivity (LSWT)	\$0	0%	\$0	0%	\$0		
7620	Productivity (TSWT)	\$0	0%	\$0	0%	\$0		
7630	Maintenance (LSWT)	\$0	0%	\$0	0%	\$0		
7640	Maintenance (TSWT)	\$0	0%	\$0	0%	\$0		
7650	Maintenance - Aux. Syst.	\$0	0%	\$0	0%	\$0		
7660	Instr. Acc. Assessment LSWT & TSWT	\$0	0%	\$0	0%	\$0		
7700	Controls						\$24,453	
7710	Controls - Auxiliary Process Systems (from 3830)	\$1,588	15%	\$1,826	20%	\$2,191		
7720	Controls - LSWT (from 4830)	\$6,898	30%	\$8,967	20%	\$10,761		
7730	Controls - TSWT (from 5830)	\$7,372	30%	\$9,584	20%	\$11,500		
	<b>Subtotal</b>	<b>\$1,072,427</b>	<b>27%</b>	<b>\$1,363,562</b>	<b>\$84,550</b>	<b>\$1,448,112</b>	<b>\$1,448,112</b>	<b>\$1,448,112</b>
8000	Management and Support							
8100	Program Management	\$158,120	2%	\$161,379	\$0	\$161,379		\$161,379
8110	Prime Contractor's Program Office	\$74,750	0%	\$74,750	0%	\$74,750	\$92,950	
8120	Operator Training	\$2,800	0%	\$2,800	0%	\$2,800		
8130	Maintenance and Operation Support	\$15,400	0%	\$15,400	0%	\$15,400		
8140	Not used	\$0	0%	\$0	0%	\$0		
8200	Quality Assurance						\$0	
8210	Quality Assurance	\$0	0%	\$0	0%	\$0		
8300	Systems Engineering and Integration						\$0	
8310	System Engineering and Intergration	\$0	0%	\$0	0%	\$0		
8320	General Engineering	\$0	0%	\$0	0%	\$0		
8330	Performance/System Specifications	\$0	0%	\$0	0%	\$0		
8340	Construction	\$0	0%	\$0	0%	\$0		
8400	Procurement						\$0	
8410	Procurement	\$0	0%	\$0	0%	\$0		
8500	Construction Management						\$0	
8510	Not used	\$0	0%	\$0	0%	\$0		
8520	Not used	\$0	0%	\$0	0%	\$0		
8530	Not used	\$0	0%	\$0	0%	\$0		
8540	Not used	\$0	0%	\$0	0%	\$0		
8600	Site and Permits							
8700	Field Indirect	\$65,170	5%	\$68,429	0%	\$68,429	\$68,429	
	<b>Total</b>	<b>\$1,230,547</b>	<b>24%</b>	<b>\$1,524,941</b>	<b>\$84,550</b>	<b>\$1,609,490</b>	<b>\$1,609,490</b>	<b>\$1,609,490</b>
	<b>Project Assessment</b>				<b>6%</b>			<b>\$1,302,113</b>

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
	Profit							
	Bond				9%	\$137,245	\$1,662,186	
	Cost Adjustment				0.8%	\$13,297	\$1,675,483	
	Construction Cost Estimate		7	3.5%	27%	\$456,199	\$2,131,682	
	Contingency						\$2,131,682	
	SIES(Construction Management)				10%	\$213,168	\$2,344,851	
	SIES(Engineering Support)				6%	\$140,691	\$2,485,542	
	Total Construction Budget Estimate				2%	\$46,897	\$2,532,439	
	PER						\$2,532,439	
	Government Project Management					\$46,000	\$2,578,439	
	Studies				10%	\$136,356	\$2,714,795	
	Design(Including Design Management)					\$11,460	\$2,726,255	
	Real Estate					\$100,800	\$2,827,054	
	Other Burden Expense					\$0	\$2,827,054	
	Project Total					\$2,827,054		\$2,827,054



National Wind Tunnel Complex									
FSO Concept									
Draft Facility Cost Estimate									
(Dollars in Thousand)									
Concept D-5									
Consortium									
WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total	
1000 Site And Infrastructure									
1100	Site Preparation	\$58,270	15%	\$67,188	\$3,953	\$71,141		\$71,141	
1110	Investigation (Design Process Only)	\$0	0%	\$0	\$0	\$0	\$72		
1120	Clearing And Grubbing	\$46	50%	\$69	5%	\$72			
1130	Demolition	\$0	0%	\$0	\$0	\$0			
1140	Dewatering	\$0	0%	\$0	\$0	\$0			
1200 Site Improvements									
1210	Earthwork	\$1,856	15%	\$2,134	3%	\$2,198	\$5,619		
1220	Drainage	\$370	25%	\$463	3%	\$476			
1230	Roads & Paving	\$1,551	20%	\$1,861	6%	\$1,973			
1240	Rail System	\$0	0%	\$0	0%	\$0			
1250	Waterway Improvements	\$376	15%	\$432	6%	\$458			
1260	Landscaping	\$52	10%	\$57	6%	\$61			
1270	Fencing And Gates	\$371	15%	\$427	6%	\$452			
1300 Utility Supply and Distribution Systems									
1310	Central Heat Pump System	\$0	0%	\$0	0%	\$0	\$3,783		
1320	Central HVAC Chiller System	\$0	0%	\$0	0%	\$0			
1330	Water Supply And Treatment System	\$767	15%	\$882	6%	\$935			
1340	Sanitary Wastewater Collection And Treatment Sys	\$256	15%	\$294	6%	\$312			
1350	Natural Gas Distribution System	\$675	15%	\$776	6%	\$823			
1360	Yard Fire Protection System	\$937	15%	\$1,078	6%	\$1,142			
1370	Compressed Air System	\$468	15%	\$538	6%	\$570			

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
1380	Steam System	\$0	0%	\$0	0%	\$0		
1400	Yard Electrical System						\$60,399	
1410	Electrical Equipment	\$49,548	15%	\$56,980	6%	\$60,399		
1420	Electrical Material (Included In 4110)	\$0	0%	\$0	0%	\$0		
1500	Other Electrical Systems						\$1,268	
1510	Lighting Systems	\$71	20%	\$85	6%	\$90		
1520	Communication Systems	\$209	20%	\$251	6%	\$266		
1530	Security Systems	\$369	20%	\$443	6%	\$469		
1540	Grounding	\$29	20%	\$35	6%	\$37		
1550	Cathodic Protection	\$101	20%	\$121	6%	\$128		
1560	Lightning Protection	\$101	20%	\$121	6%	\$128		
1570	Freeze Protection	\$57	20%	\$68	6%	\$73		
1580	Environmental Monitoring	\$24	20%	\$29	6%	\$31		
1590	DC Power for Instrumentation	\$36	20%	\$43	6%	\$46		
2000	Buildings	\$103,074	20%	\$124,107	7,366	\$131,472		\$131,472
2100	Test Preparations/Control Building						\$66,835	
2110	LSWT/...Prep/Control	\$33,890	20%	\$40,668	6%	\$43,108		
2120	TSWT/...Prep/Control	\$18,653	20%	\$22,384	6%	\$23,727		
2200	Wind Tunnel Drive Buildings						\$8,692	
2210	LSWT/TSWT Drive Building	\$6,998	15%	\$8,048	6%	\$8,692		
2220	Not Used	\$0	0%	\$0	0%	\$0		
2300	Support Buildings						\$38,124	
2310	Model Shop And Warehouse	\$19,557	20%	\$23,468	6%	\$24,877		
2320	Support Shop Building(Included In 2110)	\$0	0%	\$0	0%	\$0		
2330	Engineering Office	\$2,051	20%	\$2,461	6%	\$2,658		
2340	Guard House	\$205	10%	\$226	6%	\$239		
2350	Outfitting	\$8,625	20%	\$10,350	0%	\$10,350		
2400	Utility Buildings						\$17,822	
2410	WT Press/Vac Building	\$5,006	20%	\$6,007	6%	\$6,488		
2420	Not Used	\$0	0%	\$0	0%	\$0		
2430	Heat Pump System Equipment Building	\$0	0%	\$0	0%	\$0		
2440	HVAC Chiller Building	\$0	0%	\$0	0%	\$0		
2450	Utility Tunnels	\$7,881	30%	\$10,245	6%	\$11,065		
2460	Other Minor Buildings	\$208	20%	\$250	6%	\$270		
2470	Motor Pool Vehicles (Transferred to 2350)	\$0	0%	\$0	0%	\$0		
3000	Auxiliary Process Systems	\$114,408	20%	\$137,429	\$8,232	\$145,661		\$145,661
3100	Test Model And Cart Transport						\$6,698	
3110	LSWT Shuttle Cart	\$2,600	30%	\$3,380	12%	\$3,786		
3120	TSWT Shuttle Cart	\$2,000	30%	\$2,600	12%	\$2,912		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
3200	Wind Tunnel Pressurization/Vacuum System							
3210	Compressors, Driers, Pumps, Etc.	\$28,931	20%	\$34,717	3%	\$35,759	\$82,850	
3220	Heaters And Coolers	\$915	20%	\$1,098	5%	\$1,153		
3230	Drier System	\$5,821	20%	\$6,985	1%	\$7,055		
3240	Filters	\$962	20%	\$1,154	1%	\$1,166		
3250	Distribution Piping	\$14,474	20%	\$17,369	10%	\$19,106		
3260	Storage Tanks	\$11,761	15%	\$13,525	6%	\$14,337		
3270	Muffler Towers	\$1,394	15%	\$1,603	6%	\$1,699		
3280	Vacuum System	\$2,209	10%	\$2,430	6%	\$2,576		
3400	Cooling System						\$15,114	
3410	Cooling Towers	\$4,854	20%	\$5,825	1%	\$5,883		
3420	Cw Circ Pumps & Motors	\$3,581	20%	\$4,297	1%	\$4,340		
3430	Miscellaneous Equipment	\$138	20%	\$166	8%	\$179		
3440	Distribution System Piping	\$3,636	20%	\$4,363	8%	\$4,712		
3500	Not Used							
3600	Miscellaneous Support Systems						\$30,592	
3610	Tunnel Cleaning System	\$3,600	30%	\$4,680	10%	\$5,148		
3620	Calibration System (High Pressure Air/Model Prop.)	\$18,505	25%	\$23,131	10%	\$25,444		
3630	Compressor Blade Handling System(Transferred to	\$0	0%	\$0	0%	\$0		
3700	Scavenging And Fire Suppression System							
3710	Combustible Gas Scavenging System (Not used)	\$0	0%	\$0	0%	\$0	\$0	
3720	Tunnel Fire Suppression System (Not used)	\$0	0%	\$0	0%	\$0		
3800	Aux. Electr Control Systems And Data Acquisition						\$4,262	
3810	Electrical Equipment	\$3,496	15%	\$4,020	6%	\$4,262		
3820	Electrical Bulks(Included in 3810)	\$0	0%	\$0	0%	\$0		
3830	Control System (Transferred to 7710)	\$0	0%	\$0	0%	\$0		
3840	Data Acquisition And Processing Systems (Transfer	\$0	0%	\$0	0%	\$0		
3900	Auxiliary Test And Validation							
3910	Test And Validation	\$1,510	10%	\$1,661	1%	\$1,678	\$2,516	
3920	Calibration	\$755	10%	\$831	1%	\$839		
3A00	Productivity Provisions						\$3,629	
3A10	Productivity Provisions	\$3,266	10%	\$3,593	1%	\$3,629		
4000	Low Speed Wind Tunnel	\$386,622	32%	\$509,999	\$28,359	\$538,358	\$538,358	
4100	LSWT Enclosure							
4110	Foundation	\$14,359	20%	\$17,231	8%	\$18,609	\$36,811	
4120	Enclosure	\$12,478	20%	\$14,974	8%	\$16,171		
4130	Acoustic Insulation	\$561	20%	\$673	6%	\$714		
4140	Electrical Services	\$544	15%	\$626	6%	\$663		
4150	Mechanical Services	\$536	15%	\$616	6%	\$653		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
4200	LSWT Pressure Shell							
4210	LSWT Support Foundation( Incl. in 4110)	\$0	0%	\$0	0%	\$0	\$198,433	
4220	LSWT Support Structure	\$16,400	25%	\$20,500	3%	\$21,115		
4230	LSWT Pressure Shell	\$139,073	25%	\$173,841	2%	\$177,318		
4300	LSWT Pressure Isolation System						\$13,243	
4310	LSWT Isolation Valves	\$7,380	60%	\$11,808	10%	\$12,989		
4320	LSWT Personnel Access (Not used)	\$0	0%	\$0	0%	\$0		
4330	Hydraulic Power Unit	\$186	30%	\$242	5%	\$254		
4340	Exhaust Silencer (Transferred to 3270)	\$0	0%	\$0	0%	\$0		
4400	LSWT Flow Internals						\$62,892	
4410	Turning Vanes	\$8,886	30%	\$11,552	10%	\$12,707		
4420	Honeycomb	\$3,347	30%	\$4,351	10%	\$4,786		
4430	Screens	\$3,116	30%	\$4,051	10%	\$4,456		
4440	Internal Heat Exchanger	\$9,685	20%	\$11,622	5%	\$12,203		
4450	Settling Chamber Liner	\$15,687	30%	\$20,393	10%	\$22,432		
4460	Plenum Evacuation System (Not used)	\$0	0%	\$0	0%	\$0		
4470	Gas Manifolding(Not used)	\$0	0%	\$0	0%	\$0		
4480	High Speed Diffuser	\$2,220	30%	\$2,886	10%	\$3,175		
4490	Acoustic Treatment for nacelles	\$2,027	30%	\$2,635	10%	\$2,899		
44A0	Compressor FOD Protection	\$164	30%	\$213	10%	\$235		
44B0	Acoustic Baffles (Not used)	\$0	0%	\$0	0%	\$0		
44C0	Tunnel Cleaning System(Transferred to 3610)	\$0	0%	\$0	0%	\$0		
4500	Test Plenum						\$117,712	
4510	Subsonic Nozzle(Transferred to 4450)	\$0	0%	\$0	0%	\$0		
4520	Flutter Test Section (Not in Concept )	\$0	0%	\$0	0%	\$0		
4530	Open Jet Test Section	\$9,306	60%	\$14,890	15%	\$17,123		
4540	Moveable Plenum	\$11,841	40%	\$16,577	8%	\$17,904		
4550	Not used	\$0	0%	\$0	0%	\$0		
4560	Observation System	\$385	40%	\$539	10%	\$593		
4570	Test Section Carts	\$40,677	60%	\$65,083	12%	\$72,893		
4580	Preparation Hall Shuttle Cart	\$0	0%	\$0	0%	\$0		
4590	Anechoic Chamber	\$6,433	30%	\$8,363	10%	\$9,199		
4600	Test Support Equipment						\$20,315	
4610	Vertical Strut Assembly (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
4620	Floor Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4630	Half Model Mount (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4640	Moving Ground Plane (Transferred to 4570)	\$0	0%	\$0	0%	\$0		
4650	Elevated Ground Plane	\$1,788	50%	\$2,682	10%	\$2,950		
4660	Inverted Ground Plane	\$1,788	50%	\$2,682	10%	\$2,950		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
4670	Sting (Transferred to 7430)	\$0	0%	\$0	0%	\$0		
4680	External Balance	\$9,900	40%	\$13,860	4%	\$14,414		
4700	Compressor and Drive System						\$55,790	
4710	Rotor Hub/Blades	\$9,750	30%	\$12,675	3%	\$13,055		
4720	Shaft/Bearings/Clutch	\$2,960	25%	\$3,700	2%	\$3,774		
4730	Nacelles/Fairings and Supports	\$2,200	30%	\$2,860	5%	\$3,003		
4740	Gearbox	\$0	0%	\$0	0%	\$0		
4750	Lubrication and Cooling System	\$200	20%	\$240	5%	\$252		
4760	Motor	\$4,500	20%	\$5,400	1%	\$5,454		
4770	Motor Drive Controls	\$13,500	20%	\$16,200	2%	\$16,524		
4780	Compressor Pressure Shell/Stators/GV/OGV	\$8,800	50%	\$13,200	4%	\$13,728		
4800	Electrical, Controls System and Data Acquisition						\$0	
4810	Electrical Equipment (Transferred to 1410)	\$0	0%	\$0	0%	\$0		
4820	Electrical Materials (Transferred to 1420)	\$0	0%	\$0	0%	\$0		
4830	Control and Instrumentation (Transferred to 7720)							
4840	Data Acquisition and Processing Systems (Transferred to 7720)							
4900	Test & Validation							
4910	Test and Validation	\$7,960	10%	\$8,756	1%	\$8,844	\$12,921	
4920	Calibration	\$3,670	10%	\$4,037	1%	\$4,077		
4A00	Productivity Provisions						\$20,241	
4A10	Productivity Provisions	\$14,315	40%	\$20,041	1%	\$20,241		
5000	Transonic Wind Tunnel (TSWT)	\$320,997	29%	\$415,530	\$23,149	\$438,679		\$438,679
5100	TSWT Enclosure							
5110	Foundation	\$8,326	20%	\$9,991	8%	\$10,790	\$21,595	
5120	Enclosure	\$7,487	20%	\$8,984	8%	\$9,703		
5130	Acoustic Insulation	\$284	20%	\$341	8%	\$361		
5140	Electrical Services	\$306	15%	\$352	8%	\$373		
5150	Mechanical Services	\$301	15%	\$346	8%	\$367		
5200	Pressure Vessels						\$59,710	
5210	Foundations	\$0	0%	\$0	0%	\$0		
5220	Shell Support System	\$4,700	25%	\$5,875	5%	\$6,169		
5230	TSWT Pressure Shell	\$40,793	25%	\$50,991	5%	\$53,541		
5300	Pressure Isolation System						\$8,442	
5310	TSWT Isolation Valves	\$3,570	100%	\$7,140	15%	\$8,211		
5320	TSWT Personnel Access	\$0	0%	\$0	0%	\$0		
5330	Hydraulic Power Unit	\$150	40%	\$210	10%	\$231		
5400	TSWT Flow Internals						\$85,304	
5410	Turning Vanes	\$4,275	20%	\$5,130	10%	\$5,643		
5420	Honeycomb	\$1,019	30%	\$1,325	10%	\$1,457		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
5430	Screens	\$1,400	30%	\$1,820	10%	\$2,002		
5440	Internal Heat Exchanger	\$8,056	30%	\$10,473	10%	\$11,520		
5450	Settling Chamber Liner	\$2,040	40%	\$2,856	10%	\$3,142		
5460	Plenum Evacuation System	\$23,240	20%	\$27,888	5%	\$29,282		
5470	Acoustic Baffles	\$600	20%	\$720	15%	\$828		
5480	Flexible Nozzle	\$13,600	30%	\$17,680	15%	\$20,332		
5490	Compressor FOD Protection	\$3,400	20%	\$4,080	15%	\$4,692		
54A0	Choke System	\$3,100	30%	\$4,030	20%	\$4,836		
54B0	High Speed Diffuser Liner	\$975	40%	\$1,365	15%	\$1,570		
54C0	Ejection System	\$0	30%	\$0	12%	\$0		
5500	TSWT Test Plenum						\$79,595	
5510	Test Section	\$47,430	40%	\$66,402	7%	\$71,050		
5520	Moveable Plenum	\$5,500	30%	\$7,150	15%	\$8,223		
5530	Observation System	\$200	40%	\$280	15%	\$322		
5540	Preparation Hall Shuttle Cart	\$0	0%	\$0	0%	\$0		
5600	TSWT Test Support Equipment						\$6,406	
5610	Model Support (incl. in 5510)	\$0	0%	\$0	0%	\$0		
5620	Floor Mounts (Interface only)	\$0	0%	\$0	0%	\$0		
5630	Half Model Mounts (Interface only)	\$0	0%	\$0	0%	\$0		
5640	Stings and Booms (incl. in 7440)	\$0	0%	\$0	0%	\$0		
5650	External Balance	\$4,400	40%	\$6,160	4%	\$6,406		
5660	Other Test Support Equipment (incl. in 7740)	\$0	0%	\$0	0%	\$0		
5700	TSWT Compressor Drive System						\$150,176	
5710	Rotor Hub/Blades	\$27,020	40%	\$37,828	2%	\$38,585		
5720	Shaft/Bearings/Clutch	\$7,660	35%	\$10,341	2%	\$10,548		
5730	Nacelles/Fairings and Supports	\$6,900	40%	\$9,660	5%	\$10,143		
5740	Compressor Pressure Shell/Stators/GV/OGV	\$12,660	40%	\$17,724	4%	\$18,433		
5750	Lubrication & Cooling System	\$340	20%	\$408	5%	\$428		
5760	Motors	\$14,750	20%	\$17,700	1%	\$17,877		
5770	Motor Controls	\$44,250	20%	\$53,100	2%	\$54,162		
5780	Gearbox Included With 3530	\$0	0%	\$0	0%	\$0		
5800	TSWT Elec. Control Systems and Data Acquisition						\$0	
5810	Electrical Equipment	\$0	0%	\$0	0%	\$0		
5820	Electrical Materials	\$0	0%	\$0	0%	\$0		
5830	Control Systems (Transferred to 7730)							
5840	Data Acquisition and Data Processing Systems (Transferred to 7230)							
5900	TSWT Test and Validation, Calibration						\$14,780	
5910	Test and Validation	\$9,085	10%	\$9,994	1%	\$10,093		
5920	Calibration	\$4,218	10%	\$4,640	1%	\$4,686		

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
5A00	Productivity Items							
5A10	Productivity Items	\$8,962	40%	\$12,547		\$12,672	\$12,672	
7000	Operations (LSWT & TSWT)	\$69,056	23%	\$109,310	1%	\$122,800		
7100	Calibration							\$122,800
7110	Auxiliary Process System Calibration	\$0	0%	\$0	0%	\$0	\$25,834	
7120	Airflow Calibration Lab	\$2,785	50%	\$4,178	12%	\$4,679		
7130	Balance Calibration Lab	\$11,130	20%	\$13,356	20%	\$16,027		
7140	Structural Calibration Lab	\$198	10%	\$218	5%	\$229		
7150	Instrument Calibration Lab	\$2,977	10%	\$3,275	10%	\$3,602		
7160	Calibration Hardware - LSWT	\$322	20%	\$386	25%	\$483		
7170	Calibration Hardware - TSWT	\$322	20%	\$386	25%	\$483		
7180	Calibration Model	\$204	30%	\$265	25%	\$332		
7190	External Balance Calibrator	\$0	40%	\$0	20%	\$0		
7200	Data Acquisition System							
7210	Data Acquisition System - Aux. Systems (from 384C)	\$0	0%	\$0	0%	\$0	\$28,659	
7220	Data Acquisition System - LSWT (from 4840)	\$12,849	20%	\$15,419	5%	\$16,190		
7230	Data Acquisition System - TSWT (from 5840)	\$9,896	20%	\$11,875	5%	\$12,469		
7300	Wind Tunnel Balance							
7310	Balance (Internal) LSWT	\$1,908	40%	\$2,671	25%	\$3,339	\$6,519	
7320	Balance (Internal) TSWT	\$2,120	20%	\$2,544	25%	\$3,180		
7400	Models and Models Supports							
7410	Model Handling Equipment (LSWT)(From 3120)	\$271	20%	\$325	6%	\$345	\$5,083	
7420	Model Handling Equipment (TSWT)	\$271	20%	\$325	6%	\$345		
7430	Stings and Struts (LSWT)	\$1,502	30%	\$1,953	16%	\$2,265		
7440	Stings and Struts TSWT	\$1,529	20%	\$1,835	16%	\$2,128		
7450	Acoustic Traverse Rake(Included In 4530)	\$0	0%	\$0	0%	\$0		
7500	Instrumentation							
7510	Test (LSWT)	\$10,403	20%	\$12,484	6%	\$13,233	\$32,253	
7520	Test (TSWT)	\$7,719	20%	\$9,263	6%	\$9,819		
7530	Calibration (LSWT)	\$162	20%	\$194	18%	\$229		
7540	Calibration (TSWT)	\$162	20%	\$194	18%	\$229		
7550	Acoustics (LSWT)	\$392	20%	\$470	10%	\$517		
7560	Acoustics (TSWT)	\$0	0%	\$0	0%	\$0		
7570	Processes (LSWT)	\$2,173	20%	\$2,608	12%	\$2,921		
7580	Process (TSWT)	\$2,218	20%	\$2,662	12%	\$2,981		
7590	Hardware Integ. (LSWT)	\$479	15%	\$551	8%	\$595		
75A0	Hardware Integ. (TSWT)	\$479	15%	\$551	8%	\$595		
75B0	Aux. process Instr, LSWT & BWT	\$727	30%	\$945	20%	\$1,134		
7600	Operations Integration Analysis Plan (Incl. In 8350)						\$0	

WBS No.	Item and Description	Engineering Estimate	Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
7610	Productivity (LSWT)	\$0	0%	\$0	0%	\$0		
7620	Productivity (TSWT)	\$0	0%	\$0	0%	\$0		
7630	Maintenance (LSWT)	\$0	0%	\$0	0%	\$0		
7640	Maintenance (TSWT)	\$0	0%	\$0	0%	\$0		
7650	Maintenance - Aux. Syst.	\$0	0%	\$0	0%	\$0		
7660	Instr. Acc. Assessment LSWT & TSWT	\$0	0%	\$0	0%	\$0	\$24,453	
7700	Controls							
7710	Controls - Auxiliary Process Systems (from 3830)	\$1,588	15%	\$1,826	20%	\$2,191		
7720	Controls - LSWT (from 4830)	\$6,898	30%	\$8,967	20%	\$10,761		
7730	Controls - TSWT (from 5830)	\$7,372	30%	\$9,584	20%	\$11,500		
	Subtotal	\$1,072,427	27%	\$1,363,562	\$84,550	\$1,448,112	\$1,448,112	\$1,448,112
8000	Management and Support							
8100	Program Management							
8110	Prime Contractor's Program Office	\$52,000	0%	\$52,000	0%	\$52,000		
8120	Operator Training	\$2,800	0%	\$2,800	0%	\$2,800		
8130	Maintenance and Operation Support	\$15,400	0%	\$15,400	0%	\$15,400		
8140	Not used	\$0	0%	\$0	0%	\$0		
8200	Quality Assurance							
8210	Quality Assurance	\$0	0%	\$0	0%	\$0		
8300	Systems Engineering and Integration							
8310	System Engineering and Intergration	\$0	0%	\$0	0%	\$0		
8320	General Engineering	\$0	0%	\$0	0%	\$0		
8330	Performance/System Specifications	\$0	0%	\$0	0%	\$0		
8340	Construction	\$0	0%	\$0	0%	\$0		
8400	Procurement							
8410	Procurement	\$0	0%	\$0	0%	\$0		
8500	Construction Management							
8510	Not used	\$0	0%	\$0	0%	\$0		
8520	Not used	\$0	0%	\$0	0%	\$0		
8530	Not used	\$0	0%	\$0	0%	\$0		
8540	Not used	\$0	0%	\$0	0%	\$0		
8600	Site and Permits							
8700	Field Indirect	\$65,170	5%	\$68,429	0%	\$68,429	\$68,429	
	Total	\$1,207,797	24%	\$1,502,191	\$84,550	\$1,586,740	\$1,586,740	\$1,586,740
	Project Assessment				6%			\$1,048,222

WBS No.	Item and Description	Engineering Estimate		Risk Factor %	Const. Cost	Design Estimate %	Item Total	Subtotal	Total
		Estimate	%						
	Profit					0%	\$0	\$1,502,191	
	Bond					0.8%	\$12,018	\$1,514,208	
	Cost Adjustment			6	3.50%	23%	\$347,140	\$1,861,349	
	Construction Cost Estimate							\$1,861,349	
	Contingency					20%	\$372,270	\$2,233,618	
	SIES(Construction Management)					6%	\$134,017	\$2,367,636	
	SIES(Engineering Support)					2%	\$44,672	\$2,412,308	
	Total Construction Budget Estimate							\$2,412,308	
	PER						\$0	\$2,412,308	
	Government Project Management						\$28,645	\$2,440,953	
	Studies						\$8,660	\$2,449,613	
	Design(Including Design Management)						\$100,800	\$2,550,412	
	Real Estate						\$0	\$2,550,412	
	Other Burden Expense						\$0	\$2,550,412	
	Project Total						\$2,550,412		\$2,550,412



**National Wind Tunnel Complex**  
**Joint Industry Government Team**

**Appendix 4**

**Concept D - Option 5**

**Consortium Procurement**

**Program Schedule**



# NATIONAL WIND TUNNEL COMPLEX

## Milestone Schedule

(Calendar Years)

ID	Name	1994				1995				1996				1997				1998				1999				2000				2001				2002			
		01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04
1	NWTC - Project Start	▽																																			
6	Site - Preferred Site Selected				▽																																
256	NWTC - Project in White House Budget (1 Jan 95)				▽																																
28	LSWT - Pressure Shell: Contractor Selected								▽																												
29	TSWT - Pressure Shell: Contractor Selected								▽																												
25	LSWT - Compressor & Drive Sys: Contractor Selected								▽																												
30	TSWT - Compressor & Drive Sys: Contractor Selected								▽																												
257	NWTC - Project Approved by Congress (1 Oct 95)								▽																												
178	Site - Site Approved for Construction								▽																												
47	LSWT - Compressor & Drive Sys: Award Contract								▽																												
48	LSWT - Pressure Shell: Award Contract								▽																												
49	TSWT - Pressure Shell: Award Contract								▽																												
50	TSWT - Compressor & Drive Sys: Award Contract								▽																												
21	Site - Master Site Plan Complete								▽																												
61	LSWT - Test Sect & Carts: Contractor Selected													▽																							
70	TSWT - Test Sect & Carts: Contractor Selected													▽																							
220	LSWT - Drive Motor & Controls: Receive on Site													▽																							
88	TSWT - Pressure Shell: All Material Received on Site													▽																							
167	LSWT - Heat Exchanger: Receive on Site													▽																							
215	TSWT - Drive Motor & Controls: Receive on Site													▽																							
85	LSWT - Pressure Shell: All Material Received on Site													▽																							
171	TSWT - Heat Exchanger: Receive on Site													▽																							
84	LSWT - Compressor: Receive on Site													▽																							
89	TSWT - Compressor: Receive on Site													▽																							
187	LSWT - External Balances: Receive on Site													▽																							
199	LSWT - Tunnel Internals: Receive on Site													▽																							
205	TSWT - Tunnel Internals: Receive on Site													▽																							
193	TSWT - External Balance: Receive on Site													▽																							
161	TSWT - Ready to Test Models													▽																							

# NATIONAL WIND TUNNEL COMPLEX

## Milestone Schedule (Calendar Years)

ID	Name	1994				1995				1996				1997				1998				1999				2000				2001				2002			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4				
160	LSWT - Ready to Test Models																																				
162	NWTC - Project Complete																																				

# NATIONAL WIND TUNNEL COMPLEX

## Program Schedule

(Calendar Years)

ID	Name	1994		1995		1996		1997		1998		1999		2000		2001		2002		
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
1	NWTC - Project Start	▽																		
2	Studies - Risk Reduction Contracts: Acquire																			
254	NWTC - Joint Venture: Formation																			
255	NWTC - Joint Venture Sole Source Contract: Acquire																			
4	Site - Site Selection Process: Conduct (Multi EIS)																			
5	Studies - Risk Reduction Process: Conduct																			
3	NWTC - Joint Venture Project Office: Formation																			
253	NWTC - Project Management & Support (Level of Effort)																			
208	NWTC - Tunnel Design Requirements: Define																			
6	NWTC - Preliminary Tunnel Design: Bid & Let Contract																			
177	Site - A&E Master Site Plan: Acquire Contract																			
210	NWTC - Each Tunnel's Pressure Shell: Prepare RFP																			
211	NWTC - Each Tunnel's Drive System: Prepare RFP																			
209	NWTC - Productivity & Maintainability Model: Develop																			
11	LSWT - Compressor & Drive Sys: Establish Final Performance Specs																			
14	TSWT - Final Lines & Loads: Develop																			
15	LSWT - Final Lines & Loads: Develop																			
18	TSWT - Compressor & Drive Sys: Establish Final Performance Specs																			
10	NWTC - Preliminary Tunnel Design: Conduct																			
8	Site - Preferred Site Selected																			
7	Site - Site Acq. Process: Conduct (Write Final EIS, Acquire Title, etc.)																			
256	NWTC - Project In White House Budget (1 Jan 95)																			
9	Site - Preliminary Master Site Plan: A&E Develop																			
12	LSWT - Compressor & Drive Sys: Contractors Prepare RFP Response																			
19	TSWT - Compressor & Drive Sys: Contractor Prepare RFP Response																			
16	LSWT - Pressure Shell: Contractors Prepare RFP Response																			
17	TSWT - Pressure Shell: Contractors Prepare RFP Response																			
20	LSWT - Compressor & Drive Sys: Evaluate RFP Responses																			
24	TSWT - Compressor & Drive Sys: Evaluate RFP Responses																			

# NATIONAL WIND TUNNEL COMPLEX

## Program Schedule (Calendar Years)

ID	Name	1994				1995				1996				1997				1998				1999				2000				2001				2002			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4				
22	LSWT - Pressure Shell: Evaluate RFP Responses																																				
23	TSWT - Pressure Shell: Evaluate RFP Responses																																				
28	LSWT - Pressure Shell: Contractor Selected																																				
29	TSWT - Pressure Shell: Contractor Selected																																				
25	LSWT - Compressor & Drive Sys: Contractor Selected																																				
30	TSWT - Compressor & Drive Sys: Contractor Selected																																				
257	NWTC - Project Approved by Congress (1 Oct 95)																																				
178	Site - Site Approved for Construction																																				
31	LSWT - Compressor & Drive Sys: Contractor Develop Final Cost & Sched																																				
34	LSWT - Pressure Shell: Contractor Develop Final Cost & Schedule																																				
35	TSWT - Pressure Shell: Contractor Develop Final Cost & Schedule																																				
36	TSWT - Compressor & Drive Sys: Contractor Develop Final Cost & Sched																																				
13	Site - Final Master Site Plan: A&E Develop																																				
38	LSWT - Compressor & Drive Sys: Final Bid Evaluation																																				
42	LSWT - Pressure Shell: Final Bid Evaluation																																				
43	TSWT - Pressure Shell: Final Bid Evaluation																																				
44	TSWT - Compressor & Drive Sys: Final Bid Evaluation																																				
47	LSWT - Compressor & Drive Sys: Award Contract																																				
48	LSWT - Pressure Shell: Award Contract																																				
49	TSWT - Pressure Shell: Award Contract																																				
50	TSWT - Compressor & Drive Sys: Award Contract																																				
212	TSWT - Drive Motor & Controls: Detail Design																																				
217	LSWT - Drive Motor & Controls: Detail Design																																				
56	LSWT - Pressure Shell: Detail Design																																				
57	TSWT - Pressure Shell: Detail Design																																				
54	LSWT - Compressor: Conduct Detail Design																																				
59	TSWT - Compressor: Conduct Detail Design																																				
258	NWTC - Final Design Contract: Let																																				
218	LSWT - Drive Motor & Controls: Manufacture																																				

# NATIONAL WIND TUNNEL COMPLEX

## Program Schedule (Calendar Years)

ID	Name	1994	1995	1996	1997	1998	1999	2000	2001	2002
213	TSWT - Drive Motor & Controls: Manufacture									
21	Site - Master Site Plan Complete									
26	Site - Site & Utilities: Design									
27	Bldgs. - NWTC Buildings: Design									
55	LSWT - Pressure Shell: Order Forgings									
58	TSWT - Pressure Shell: Order Forgings									
62	LSWT - Compressor: Manufacture									
65	LSWT - Pressure Shell: Order Material									
66	TSWT - Pressure Shell: Order Material									
69	TSWT - Compressor: Manufacture									
100	NWTC - DAS: Define Requirements									
40	TSWT - Tunnel Final Design: Conduct									
41	LSWT - Tunnel Final Design: Conduct									
68	TSWT - Pressure Shell: Manufacture Forgings									
63	LSWT - Pressure Shell: Manufacture Forgings									
64	LSWT - Pressure Shell: Shop Fabrication									
182	LSWT - Heat Exchanger: Aero Verify Configuration									
183	TSWT - Heat Exchanger: Aero Verify Configuration									
67	TSWT - Pressure Shell: Shop Fabrication									
227	LSWT - Rolling Plenum: Manufacture, Ship & Install									
228	TSWT - Rolling Plenum: Manufacture, Ship & Install									
184	LSWT - External Balances: Bid & Let Contract									
32	Site - Site & Utilities Construction: Bid & Let Contracts									
46	LSWT - Test Sect & Carts: Contractors Prepare RFP Response									
101	NWTC - DAS: Bid & Let Contract									
165	LSWT - Heat Exchanger: Bid & Let Contract									
169	TSWT - Heat Exchanger: Bid & Let Contract									
37	Site - Electrical Utilities: Installation									
39	Site - Prepare Site									

**Program Schedule**  
**(Calendar Years)**

Mar 31 '94

# NATIONAL WIND TUNNEL COMPLEX

## Program Schedule (Calendar Years)

ID	Name	1994	1995	1996	1997	1998	1999	2000	2001	2002
221	LSWT - Drive Motor & Controls: Install									
82	Bldgs. - TSWT Test Prep & Control Bldg.: Construct									
78	TSWT - Pressure Shell: Site Fabrication & Erection									
75	LSWT - Pressure Shell: On-Site Fabrication & Erection									
222	NWTC - Plenum Evacuation Plant: Manufacture & Ship									
223	NWTC - HP Air Plant: Manufacture & Ship									
224	NWTC - Tunnel Pressurization Plant: Manufacture & Ship									
225	NWTC - Cooling Water Plant: Manufacture & Ship									
226	NWTC - Aux. Systems (Other): Manufacture & Ship									
240	NWTC - Aux. Systems Productivity Items: Manufacture & Ship									
244	LSWT - Ground Planes: Manufacture & Ship									
249	NWTC - Operations Equip. & Instruments: Manufacture & Ship									
88	TSWT - Pressure Shell: All Material Received on Site									
214	TSWT - Drive Motor & Controls: Shipping to Site									
131	TSWT - Flex Nozzle: Bid & Let Contract									
231	TSWT - Productivity Items: Bid & Let Contract									
235	LSWT - Productivity Items: Bid & Let Contract									
167	LSWT - Heat Exchanger: Receive on Site									
215	TSWT - Drive Motor & Controls: Receive on Site									
216	TSWT - Drive Motor & Controls: Install									
71	Bldgs. - LSWT Test Prep & Control Bldg.: Construct									
85	LSWT - Pressure Shell: All Material Received on Site									
144	TSWT - Flex Nozzle: Manufacture									
232	TSWT - Productivity Items: Manufacture & Ship									
236	LSWT - Productivity Items: Manufacture & Ship									
73	LSWT - Compressor: Shipping to Site									
127	TSWT - Model Support Sys: Receive on Site									
136	LSWT - Model Support Sys: Receive on Site									
171	TSWT - Heat Exchanger: Receive on Site									

**Program Schedule  
(Calendar Years)**

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# NATIONAL WIND TUNNEL COMPLEX

## Program Schedule (Calendar Years)

ID	Name	1994	1995	1996	1997	1998	1999	2000	2001	2002
242	NWTC - Aux. Systems Productivity Items: Checkout									
246	LSWT - Ground Planes: Checkout									
251	NWTC - Operations Equip. & Instruments: Checkout									
109	TSWT - DAS: Checkout									
119	LSWT - DAS: Checkout									
77	TSWT - Isolation Valves: Checkout									
45	Bldgs. - Tunnel Enclosure: Construct									
148	TSWT - Flex Nozzle: Receive on Site									
233	TSWT - Productivity Items: Install / Accept									
237	LSWT - Productivity Items: Install									
87	TSWT - Pressure Shell: Conduct Hydrostatic Test									
186	LSWT - External Balances: Shipping to Site									
187	LSWT - External Balances: Receive on Site									
234	TSWT - Productivity Items: Checkout									
238	LSWT - Productivity Items: Checkout									
172	TSWT - Heat Exchanger: Install									
164	TSWT - Flex Nozzle: Install									
137	TSWT - Model Support Sys: Install									
123	TSWT - Electrical System: Install									
94	TSWT - Compressor: Install									
198	LSWT - Tunnel Internals: Shipping to Site									
204	TSWT - Tunnel Internals: Shipping to Site									
199	LSWT - Tunnel Internals: Receive on Site									
205	TSWT - Tunnel Internals: Receive on Site									
200	LSWT - Tunnel Internals: Install									
206	TSWT - Tunnel Internals: Install									
76	LSWT - Isolation Valves: Checkout									
90	Bldgs. - Drive Bldg.: Construct									
192	TSWT - External Balance: Shipping to Site									

# NATIONAL WIND TUNNEL COMPLEX

## Program Schedule

(Calendar Years)

ID	Name	1994				1995				1996				1997				1998				1999				2000				2001				2002			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4				
247	NWTC - Aux. Systems (Other): Checkout																																				
147	TSWT - Choke System: Receive on Site																																				
153	TSWT - Flex Nozzle: Checkout																																				
91	LSWT - Test Sect. & Carts: Shipping to Site																																				
95	TSWT - Test Sect. & Carts: Shipping to Site																																				
193	TSWT - External Balance: Receive on Site																																				
86	LSWT - Pressure Shell: Conduct Hydrostatic Test																																				
163	TSWT - Choke System: Install																																				
168	LSWT - Heat Exchanger: Install																																				
181	NWTC - Cooling Water Plant: Checkout																																				
96	TSWT - Test Sect. & Carts: Install																																				
97	LSWT - Test Sect. & Carts: Install																																				
92	LSWT - Compressor: Install																																				
116	LSWT - Electrical System: Install																																				
152	TSWT - Choke System: Checkout																																				
112	LSWT - C&I: Receive on Site																																				
122	TSWT - C&I: Receive on Site																																				
129	TSWT - Electrical Systems: Checkout																																				
201	LSWT - Tunnel Internals: Inspect / Accept																																				
207	TSWT - Tunnel Internals: Inspect / Accept																																				
117	LSWT - C&I: Install																																				
128	TSWT - C&I: Install																																				
141	TSWT - Cooling System: Checkout																																				
151	TSWT - Plenum Evacuation Sys: Checkout																																				
99	TSWT - Compressor & Drive Sys: Checkout																																				
194	TSWT - External Balance: Install																																				
188	LSWT - External Balances: Install																																				
180	NWTC - Tunnel Pressurization Plant Checkout																																				
98	LSWT - Compressor & Drive Sys: Checkout																																				

# NATIONAL WIND TUNNEL COMPLEX

## Program Schedule (Calendar Years)

ID	Name	1994				1995				1996				1997				1998				1999				2000				2001				2002			
		01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04	01	02	03	04
195	TSWT - External Balance: Checkout																																				
124	LSWT - Electrical System: Checkout																																				
189	LSWT - External Balances: Checkout																																				
139	TSWT - Test Sect. & Carts: Checkout																																				
146	TSWT - Model Support Sys: Checkout																																				
134	LSWT - Cooling System: Checkout																																				
125	LSWT - C&I: Checkout																																				
252	TSWT - C&I Checkout																																				
133	LSWT - Tunnel Pressurization Sys: Checkout																																				
140	TSWT - Tunnel Pressurization Sys: Checkout																																				
179	NWTC - HP Air Plant: Checkout																																				
135	LSWT - Test Sect. & Carts: Checkout																																				
145	LSWT - Model Support Sys: Checkout																																				
132	LSWT - HP Air System: Checkout																																				
142	TSWT - HP Air System: Checkout																																				
150	TSWT - C&I / DAS: Integrated Systems Checkout																																				
149	LSWT - C&I / DAS: Integrated Systems Checkout																																				
155	TSWT - Integrated Tunnel Systems: Checkout																																				
157	TSWT - Integrated Tunnel Systems: Conduct Post-Checkout Repairs																																				
154	LSWT - Integrated Tunnel Systems: Checkout																																				
156	LSWT - Integrated Tunnel Systems: Conduct Post-Checkout Repairs																																				
159	TSWT - Calibration																																				
158	LSWT - Calibration																																				
161	TSWT - Ready to Test Models																																				
160	LSWT - Ready to Test Models																																				
162	NWTC - Project Complete																																				

# NATIONAL WIND TUNNEL COMPLEX

Joint Industry Government Team

## Task Sheet

ID	WBS	Name	Duration	Predecessors	Early Start	Late Start	Early Finish	Late Finish	Total Slack
1	8000	NWTC - Project Start	0w		1 Apr '94	1 Apr '94	1 Apr '94	1 Apr '94	0d
2	9800	Studies - Risk Reduction Contracts: Acquire	4w	1	1 Apr '94	30 Aug '94	28 Apr '94	27 Sep '94	105d
254	0	NWTC - Joint Venture: Formation	13w	1	1 Apr '94	1 Apr '94	1 Jul '94	1 Jul '94	0d
255	0	NWTC - Joint Venture Sole Source Contract: Acquire	13w	1	1 Apr '94	1 Apr '94	1 Jul '94	1 Jul '94	0d
4	8540	Site - Site Selection Process: Conduct (Multi EIS)	35w	1	1 Apr '94	1 Apr '94	9 Dec '94	6 Dec '94	0d
5	9800	Studies - Risk Reduction Process: Conduct	26w	2	29 Apr '94	28 Sep '94	2 Nov '94	6 Apr '95	105d
3	8100	NWTC - Joint Venture Project Office: Formation	4w	254,255	5 Jul '94	5 Jul '94	1 Aug '94	1 Aug '94	0d
253	8000	NWTC - Project Management & Support (Level of Effort)	387w	254	5 Jul '94	19 Jul '94	20 Mar '02	3 Apr '02	10d
208	8300	NWTC - Tunnel Design Requirements: Define	4w	3	2 Aug '94	2 Aug '94	20 Aug '94	29 Aug '94	0d
6	9900	NWTC - Preliminary Tunnel Design: Bid & Let Contract	13w	208,3	30 Aug '94	30 Aug '94	2 Dec '94	2 Dec '94	0d
177	9900	Site - A&E Master Site Plan: Acquire Contract	17w	6	5 Dec '94	14 Apr '95	6 Apr '95	14 Aug '95	90d
210	9900	NWTC - Each Tunnel's Pressure Shell: Prepare RFP	17w	10SS	5 Dec '94	8 Aug '95	6 Apr '95	8 Dec '95	170d
211	9900	NWTC - Each Tunnel's Drive System: Prepare RFP	17w	10SS	5 Dec '94	23 Jan '95	6 Apr '95	23 May '95	285d
209	8300	NWTC - Productivity & Maintainability Model: Develop	26w	6	5 Dec '94	12 Jun '95	9 Jun '95	15 Dec '95	130d
11	9900	LSWT - Compressor & Drive Sys: Establish Final Performance Specs	35w	10SS	5 Dec '94	15 Jan '97	14 Aug '95	22 Sep '97	530d
14	9900	TSWT - Final Lines & Loads: Develop	35w	10SS	5 Dec '94	29 Aug '95	14 Aug '95	9 May '96	185d
15	9900	LSWT - Final Lines & Loads: Develop	35w	10SS	5 Dec '94	1 Aug '95	14 Aug '95	11 Apr '96	165d
18	9900	TSWT - Compressor & Drive Sys: Establish Final Performance Specs	35w	10SS	5 Dec '94	25 Jan '96	14 Aug '95	1 Oct '96	285d
10	9900	NWTC - Preliminary Tunnel Design: Conduct	52w	5w,208FF,6,8FF+39w,256FF+48w,257FF+4w	5 Dec '94	5 Dec '94	15 Dec '95	15 Dec '95	0d
8	8540	Site - Preferred Site Selected	0w	4	9 Dec '94	9 Mar '95	9 Dec '94	9 Mar '95	60d
7	8540	Site - Site Acq. Process: Conduct (Write Final EIS, Acquire Title, etc.)	43w		12 Dec '94	12 Dec '94	18 Oct '95	18 Oct '95	0d
256	0	NWTC - Project in White House Budget (1 Jan 95)	0w	1SS+38w	3 Jan '95	3 Jan '95	3 Jan '95	3 Jan '95	0d
9	9900	Site - Preliminary Master Site Plan: A&E Develop	9w	177,6	7 Apr '95	15 Aug '95	9 Jun '95	16 Oct '95	90d
12	4700	LSWT - Compressor & Drive Sys: Contractors Prepare RFP Response	12w	211	7 Apr '95	15 May '97	30 Jun '95	8 Aug '97	530d
19	5700	TSWT - Compressor & Drive Sys: Contractor Prepare RFP Response	12w	211	7 Apr '95	24 May '96	30 Jun '95	19 Aug '96	285d
16	4200	LSWT - Pressure Shell: Contractors Prepare RFP Response	13w	210	7 Apr '95	11 Dec '95	10 Jul '95	14 Mar '96	170d
17	5200	TSWT - Pressure Shell: Contractors Prepare RFP Response	13w	210	7 Apr '95	3 May '96	10 Jul '95	5 Aug '96	270d
20	4700	LSWT - Compressor & Drive Sys: Evaluate RFP Responses	6w	12	3 Jul '95	11 Aug '97	14 Aug '95	22 Sep '97	530d
24	5700	TSWT - Compressor & Drive Sys: Evaluate RFP Responses	6w	19	3 Jul '95	20 Aug '96	14 Aug '95	1 Oct '96	285d
22	4200	LSWT - Pressure Shell: Evaluate RFP Responses	4w	16	11 Jul '95	15 Mar '96	7 Aug '95	11 Apr '96	170d
23	5200	TSWT - Pressure Shell: Evaluate RFP Responses	4w	17	11 Jul '95	6 Aug '96	7 Aug '95	3 Sep '96	270d
28	4200	LSWT - Pressure Shell: Contractor Selected	0w	22	7 Aug '95	11 Apr '96	7 Aug '95	11 Apr '96	170d
29	5200	TSWT - Pressure Shell: Contractor Selected	0w	23	7 Aug '95	3 Sep '96	7 Aug '95	3 Sep '96	270d
25	4700	LSWT - Compressor & Drive Sys: Contractor Selected	0w	20	14 Aug '95	22 Sep '97	14 Aug '95	22 Sep '97	530d
30	5700	TSWT - Compressor & Drive Sys: Contractor Selected	0w	24	14 Aug '95	1 Oct '96	14 Aug '95	1 Oct '96	285d
257	0	NWTC - Project Approved by Congress (1 Oct 95)	0w	1SS+76w	3 Oct '95	16 Nov '95	3 Oct '95	16 Nov '95	30d
178	8540	Site - Site Approved for Construction	0w	7	18 Oct '95	18 Oct '95	18 Oct '95	18 Oct '95	0d
31	4700	LSWT - Compressor & Drive Sys: Contractor Develop Final Cost & Schedule	4w	11,25,178	19 Oct '95	23 Sep '97	16 Nov '95	21 Oct '97	485d
34	4200	LSWT - Pressure Shell: Contractor Develop Final Cost & Schedule	4w	15,28,178	19 Oct '95	12 Apr '96	16 Nov '95	9 May '96	120d
35	5200	TSWT - Pressure Shell: Contractor Develop Final Cost & Schedule	4w	14,29,178	19 Oct '95	4 Sep '96	16 Nov '95	1 Oct '96	220d
36	5700	TSWT - Compressor & Drive Sys: Contractor Develop Final Cost & Schedule	4w	18,30,178	19 Oct '95	2 Oct '96	16 Nov '95	30 Oct '96	240d
13	9900	Site - Final Master Site Plan: A&E Develop	17w	9,8,178	19 Oct '95	19 Oct '95	22 Feb '96	22 Feb '96	0d
38	4700	LSWT - Compressor & Drive Sys: Final Bid Evaluation	2w	31	17 Nov '95	22 Oct '97	1 Dec '95	4 Nov '97	485d
42	4200	LSWT - Pressure Shell: Final Bid Evaluation	2w	34	17 Nov '95	10 May '96	1 Dec '95	23 May '96	120d
43	5200	TSWT - Pressure Shell: Final Bid Evaluation	2w	35	17 Nov '95	2 Oct '96	1 Dec '95	16 Oct '96	220d
44	5700	TSWT - Compressor & Drive Sys: Final Bid Evaluation	2w	36	17 Nov '95	31 Oct '96	1 Dec '95	14 Nov '96	240d
47	4700	LSWT - Compressor & Drive Sys: Award Contract	0w	38	1 Dec '95	4 Nov '97	1 Dec '95	4 Nov '97	485d
48	4200	LSWT - Pressure Shell: Award Contract	0w	42	1 Dec '95	23 May '96	1 Dec '95	23 May '96	120d
49	5200	TSWT - Pressure Shell: Award Contract	0w	43	1 Dec '95	16 Oct '96	1 Dec '95	16 Oct '96	220d
50	5700	TSWT - Compressor & Drive Sys: Award Contract	0w	44	1 Dec '95	14 Nov '96	1 Dec '95	14 Nov '96	240d
212	5700	TSWT - Drive Motor & Controls: Detail Design	26w	50	4 Dec '95	28 Nov '97	7 Jun '96	13 Aug '99	500d
217	4700	LSWT - Drive Motor & Controls: Detail Design	26w	47	4 Dec '95	21 Oct '96	7 Jun '96	8 Mar '00	725d
56	4200	LSWT - Pressure Shell: Detail Design	35w	48	4 Dec '95	24 May '96	12 Aug '96	10 Feb '98	120d

**NATIONAL WIND TUNNEL COMPLEX**  
Joint Industry Government Team  
Task Sheet

ID	WBS	Name	Duration	Predecessors	Early Start	Late Start	Early Finish	Late Finish	Total Slack
57	5200	TSWT - Pressure Shell: Detail Design	35w	49	4 Dec '95	17 Oct '96	12 Aug '96	25 Feb '98	220c
54	4700	TSWT - Compressor: Conduct Detail Design	52w	47	4 Dec '95	5 Nov '97	13 Dec '96	8 Mar '00	485c
59	5700	TSWT - Compressor: Conduct Detail Design	52w	50	4 Dec '95	15 Nov '96	13 Dec '96	13 Aug '99	240c
258	0	NWTC - Final Design Contract Let	17w	10	18 Dec '95	18 Dec '95	18 Apr '96	18 Apr '96	0c
218	4760	LSWT - Drive Motor & Controls: Manufacture	65w	217SS+4w	3 Jan '96	19 Nov '98	16 Apr '97	8 Mar '00	725c
213	5760	TSWT - Drive Motor & Controls: Manufacture	82w	212SS+4w	3 Jan '96	29 Dec '97	15 Aug '97	13 Aug '99	500c
21	9900	Site - Master Site Plan Complete	0w	13	22 Feb '96	22 Feb '96	22 Feb '96	22 Feb '96	0c
26	9900	Site - Site & Utilities: Design	26w	21	23 Feb '96	23 Feb '96	26 Aug '96	26 Aug '96	0c
27	9900	Bldgs - NWTC Buildings: Design	52w	21	23 Feb '96	23 Dec '96	5 Mar '97	5 Jan '98	210c
55	4200	LSWT - Pressure Shell: Order Forgings	9w	56SS+13w	8 Mar '96	30 May '97	9 May '96	1 Aug '97	310c
58	5200	TSWT - Pressure Shell: Order Forgings	9w	57SS+13w	8 Mar '96	25 Aug '97	9 May '96	28 Oct '97	370c
62	4700	LSWT - Compressor: Manufacture	104w	54SS+13w	8 Mar '96	11 Feb '98	1 Apr '98	8 Mar '00	485c
65	4200	LSWT - Pressure Shell: Order Material	17w	56SS+17w	5 Apr '96	25 Sep '96	5 Aug '96	3 Nov '98	120c
66	5200	TSWT - Pressure Shell: Order Material	17w	57SS+17w	5 Apr '96	20 Feb '97	5 Aug '96	28 Apr '99	220c
69	5700	TSWT - Compressor: Manufacture	121w	58SS+17w	5 Apr '96	20 Feb '97	5 Aug '96	3 Nov '98	240c
100	8300	NWTC - DAS: Define Requirements	26w	10,40SS+41SS	19 Apr '96	12 Dec '97	23 Oct '96	18 Jun '98	415c
40	9900	TSWT - Tunnel Final Design: Conduct	104w	14,178,258	19 Apr '96	10 May '96	13 May '98	4 Jun '98	15c
41	9900	LSWT - Tunnel Final Design: Conduct	104w	15,178,258	19 Apr '96	19 Apr '96	13 May '98	4 Jun '98	15c
68	5200	TSWT - Pressure Shell: Manufacture Forgings	42w	58	10 May '96	29 Oct '97	12 May '97	13 May '98	0c
63	4200	LSWT - Pressure Shell: Shop Fabrication	52w	55	10 May '96	4 Aug '97	21 May '97	28 Aug '98	370c
182	4440	LSWT - Heat Exchanger: Shop Fabrication	69w	65SS+9w,56FF+35w	10 Jun '96	2 Dec '96	21 Oct '97	20 Oct '98	120c
183	5440	TSWT - Heat Exchanger: Aero Verify Configuration	13w	40SS+13w	23 Jul '96	4 Jun '99	23 Oct '96	3 Sep '99	720c
67	5200	TSWT - Pressure Shell: Shop Fabrication	52w	41SS+13w	23 Jul '96	24 Aug '98	23 Oct '96	25 Nov '98	525c
227	4540	LSWT - Rolling Plenum: Manufacture, Ship & Install	52w	66SS+17w,57FF+35w	6 Aug '96	20 Jun '97	15 Aug '97	3 Nov '98	220c
228	5520	TSWT - Rolling Plenum: Manufacture, Ship & Install	52w	56	13 Aug '96	12 Jun '98	22 Aug '97	24 Jun '99	460c
184	4680	LSWT - External Balances: Bid & Let Contract	52w	57	13 Aug '96	26 Jun '98	22 Aug '97	9 Jul '99	470c
32	1000	Site - Site & Utilities Construction: Bid & Let Contracts	17w	41SS+17w	20 Aug '96	28 Jul '97	20 Dec '96	26 Nov '97	235c
46	4500	LSWT - Test Sect. & Carts: Contractors Prepare RFP Response	13w	21SS,26FF+13w	27 Aug '96	27 Aug '96	29 Nov '96	29 Nov '96	0c
101	7200	NWTC - DAS: Bid & Let Contract	13w	41SS+26w	24 Oct '96	23 Sep '97	28 Jan '97	26 Dec '97	230c
165	4440	LSWT - Heat Exchanger: Bid & Let Contract	13w	100	24 Oct '96	19 Jun '98	28 Jan '97	21 Sep '98	415c
169	5440	TSWT - Heat Exchanger: Bid & Let Contract	13w	182	24 Oct '96	7 Sep '98	28 Jan '97	9 Dec '99	720c
37	1000	Site - Electrical Utilities: Installation	52w	183	24 Oct '96	27 Nov '98	28 Jan '97	3 Mar '99	525c
39	1000	Site - Prepare Site	78w	32	2 Dec '96	27 Oct '99	11 Dec '97	7 Nov '00	730c
185	4680	LSWT - External Balances: Design & Manufacture	104w	32,178	2 Dec '96	2 Dec '96	18 Jun '98	3 Apr '02	0c
51	5510	TSWT - Test Sect. & Carts: Contractors Prepare RFP Response	13w	184	23 Dec '96	28 Nov '97	19 Jan '99	23 Dec '99	235c
114	5610	TSWT - Model Support Sys: Bid & Let Contract	13w	40SS+35w	31 Dec '96	26 Feb '98	2 Apr '97	28 May '98	290c
120	4610	LSWT - Model Support Sys: Bid & Let Contract	13w	40SS+35w	31 Dec '96	26 Jun '98	2 Apr '97	28 Sep '98	375c
190	5650	TSWT - External Balance: Bid & Let Contract	17w	41SS+35w	31 Dec '96	6 Jul '98	2 Apr '97	5 Oct '98	380c
53	4500	LSWT - Test Sect. & Carts: Evaluate RFP Responses	4w	40SS+35w	31 Dec '96	18 Aug '97	30 Apr '97	18 Dec '97	160c
166	4440	LSWT - Heat Exchanger: Manufacture	32w	46	29 Jan '97	29 Dec '97	26 Feb '97	27 Jan '98	230c
170	5440	TSWT - Heat Exchanger: Manufacture	64w	165	29 Jan '97	10 Dec '99	15 Sep '97	28 Jul '00	720c
103	7230	TSWT - DAS: Manufacture	65w	169	29 Jan '97	4 Mar '99	6 May '98	8 Jun '00	525c
106	7220	LSWT - DAS: Manufacture	65w	101	29 Jan '97	22 Sep '98	13 May '98	10 Jan '00	415c
61	4500	LSWT - Test Sect. & Carts: Contractor Selected	0w	101	29 Jan '97	6 Oct '98	13 May '98	25 Jan '00	425c
72	4570	LSWT - Test Sect. & Carts: Manufacture	70w	53	26 Feb '97	27 Jan '98	16 Feb '97	17 Jun '99	230c
229	4210	LSWT - Pressure Shell: Construct Foundations	13w	61	27 Feb '97	28 Jan '98	17 Jul '98	17 Jun '99	230c
230	5210	TSWT - Pressure Shell: Construct Foundations	13w	21SS,27FF+13w	6 Mar '97	6 Jan '98	5 Jun '97	5 Jun '97	0c
79	5200	TSWT - Pressure Shell: Shipping Forgings to User	9w	39SS+13w	6 Mar '97	23 Sep '97	5 Jun '97	26 Dec '97	140c
60	5500	TSWT - Test Sect. & Carts: Evaluate RFP Responses	4w	68	13 Mar '97	31 Aug '98	14 May '97	3 Nov '98	370c
121	5610	TSWT - Model Support Sys: Manufacture	52w	51	3 Apr '97	29 May '98	3 Apr '97	25 Jun '98	290c
126	4610	LSWT - Model Support Sys: Manufacture	52w	114	3 Apr '97	29 Sep '98	1 Apr '98	12 Oct '99	375c
				120	3 Apr '97	6 Oct '98	1 Apr '98	19 Oct '99	380c

**NATIONAL WIND TUNNEL COMPLEX**  
**Joint Industry Government Team**  
**Task Sheet**

ID	WBS	Name	Duration	Predecessors	Early Start	Late Start	Early Finish	Late Finish	Total Slack
219	4760	LSWT - Drive Motor & Controls: Shipping to Site	6w		17 Apr '97	9 Mar '00	29 May '97	19 Apr '00	725d
70	5500	TSWT - Test Sect. & Carts: Contractor Selected	0w		30 Apr '97	25 Jun '98	30 Apr '97	25 Jun '98	290d
93	3000	NWTC - Aux. Systems [Other]: Bid & Let Contracts	13w	40SS+52w 41SS+52w	1 May '97	27 Jun '97	1 Aug '97	29 Sep '97	40d
239	3A10	NWTC - Aux. Systems Productivity Items: Bid & Let Contract	13w	40SS+52w 41SS+52w	1 May '97	19 Jul '99	1 Aug '97	19 Oct '99	555d
243	4660	LSWT - Ground Planes: Bid & Let Contract	13w	41SS+52w	1 May '97	2 Aug '99	1 Aug '97	2 Nov '99	565d
248	7000	NWTC - Operations Equip. & Instruments: Bid & Let Contracts	13w	40SS+52w 41SS+52w	1 May '97	19 Jul '99	1 Aug '97	19 Oct '99	555d
81	5510	TSWT - Test Sect. & Carts: Manufacture	52w		1 May '97	26 Jun '98	13 May '98	9 Jul '99	290d
191	5650	TSWT - External Balance: Design & Manufacture	104w		1 May '97	19 Dec '97	26 May '99	18 Jan '00	160d
74	4200	LSWT - Pressure Shell: Shipping Forgings to User	9w		22 May '97	17 Aug '98	25 Jul '97	20 Oct '98	310d
220	4760	LSWT - Drive Motor & Controls: Receive on Site	0w		29 May '97	19 Apr '00	29 May '97	19 Apr '00	725d
221	4760	LSWT - Drive Motor & Controls: Install	26w		30 May '97	20 Apr '00	4 Dec '97	24 Oct '00	725d
82	2120	Bldgs. - TSWT Test Prep & Control Bldg.: Construct	65w	33.37FF	6 Jun '97	9 Apr '98	21 Sep '98	24 Sep '01	210d
78	5230	TSWT - Pressure Shell: Site Fabrication & Erection	69w	66FF+26w 67SS+26w 88FF+26w 230	6 Jun '97	29 Dec '97	20 Oct '98	12 May '99	140d
75	4230	LSWT - Pressure Shell: On-Site Fabrication & Erection	95w	64SS+26w 85FF+26w 65FF 229	6 Jun '97	6 Jun '97	28 Apr '99	28 Apr '99	0d
222	5460	NWTC - Plenum Evacuation Plant: Manufacture & Ship	52w		4 Aug '97	14 Oct '98	14 Aug '98	25 Oct '99	300d
223	3620	NWTC - HP Air Plant: Manufacture & Ship	52w		4 Aug '97	5 Dec '97	17 Dec '98	13 Oct '98	85d
224	3200	NWTC - Tunnel Pressurization Plant: Manufacture & Ship	52w		4 Aug '97	30 Sep '97	14 Aug '98	13 Oct '98	40d
225	3400	NWTC - Cooling Water Plant: Manufacture & Ship	52w		4 Aug '97	4 Feb '98	14 Aug '98	17 Feb '99	125d
226	3000	NWTC - Aux. Systems [Other]: Manufacture & Ship	52w		4 Aug '97	20 Jan '99	14 Aug '98	1 Feb '00	365d
240	3A10	NWTC - Aux. Systems Productivity Items: Manufacture & Ship	52w		4 Aug '97	20 Oct '99	14 Aug '98	31 Oct '00	555d
244	4660	LSWT - Ground Planes: Manufacture & Ship	52w		4 Aug '97	20 Oct '99	14 Aug '98	31 Oct '00	555d
249	7000	NWTC - Operations Equip. & Instruments: Manufacture & Ship	52w		4 Aug '97	3 Nov '98	15 Aug '97	3 Nov '98	305d
88	5200	TSWT - Pressure Shell: All Material Received on Site	0w		15 Aug '97	16 Aug '99	29 Sep '97	27 Sep '99	300d
214	5760	TSWT - Drive Motor & Controls: Shipping to Site	6w	79.67	18 Aug '97	16 Aug '99	15 Aug '97	3 Jun '99	375d
131	5460	TSWT - Flex Nozzle: Bid & Let Contract	13w	213.212	1 Sep '97	4 Mar '99	4 Dec '97	3 Jun '99	470d
235	5A10	TSWT - Productivity Items: Bid & Let Contract	13w	40SS+69w	1 Sep '97	19 Jul '99	4 Dec '97	19 Oct '99	470d
167	4440	LSWT - Heat Exchanger: Receive on Site	0w	40SS+69w	1 Sep '97	2 Aug '99	4 Dec '97	2 Nov '99	480d
215	5760	TSWT - Drive Motor & Controls: Receive on Site	0w	41SS+69w	1 Sep '97	2 Aug '99	4 Dec '97	2 Nov '99	480d
216	5760	TSWT - Drive Motor & Controls: Install	39w		15 Sep '97	28 Jul '00	15 Sep '97	28 Jul '00	720d
71	2110	Bldgs. - LSWT Test Prep & Control Bldg.: Construct	65w		29 Sep '97	27 Sep '99	29 Sep '97	27 Sep '99	500d
85	4200	LSWT - Pressure Shell: All Material Received on Site	0w	33.37FF+9w 82SS+17w	21 Oct '97	20 Oct '98	26 Jan '99	9 Oct '01	210d
144	5480	TSWT - Flex Nozzle: Manufacture	52w	74.64	21 Oct '97	10 Aug '98	26 Jan '99	9 Oct '01	210d
232	5A10	TSWT - Productivity Items: Manufacture & Ship	52w		5 Dec '97	4 Jun '99	17 Dec '98	15 Jun '00	375d
236	4A10	LSWT - Productivity Items: Manufacture & Ship	52w		5 Dec '97	20 Oct '99	17 Dec '98	31 Oct '00	470d
73	4700	LSWT - Compressor: Shipping to Site	6w	235	5 Dec '97	3 Nov '99	17 Dec '98	15 Nov '00	480d
127	5610	TSWT - Model Support Sys: Receive on Site	4w	62.54	2 Apr '98	9 Mar '00	13 May '98	19 Apr '00	485d
136	4610	LSWT - Model Support Sys: Receive on Site	4w		16 Apr '98	13 Oct '99	13 May '98	9 Nov '99	375d
171	5440	TSWT - Heat Exchanger: Receive on Site	0w	126	16 Apr '98	20 Oct '99	13 May '98	17 Nov '99	380d
84	4700	LSWT - Compressor: Receive on Site	0w	170	6 May '98	8 Jun '00	6 May '98	8 Jun '00	525d
104	7230	TSWT - DAS: Receive on Site	4w	73	13 May '98	19 Apr '00	13 May '98	19 Apr '00	485d
113	7220	LSWT - DAS: Receive on Site	4w	103	14 May '98	11 Jan '00	11 Jun '98	8 Feb '00	415d
111	3810	LSWT - Electrical System: Bid & Let Contract	9w	106	14 May '98	26 Jan '00	11 Jun '98	23 Feb '00	425d
115	3810	TSWT - Electrical System: Bid & Let Contract	9w	41	14 May '98	19 Jul '99	17 Jul '98	20 Sep '99	296d
102	7700	NWTC - C&I: Bid & Let Contract	13w	40	14 May '98	12 Jul '99	17 Jul '98	13 Sep '99	290d
130	54A0	TSWT - Choke System: Bid & Let Contract	13w	40.41	14 May '98	19 Jun '98	14 Aug '98	21 Sep '98	25d
196	5400	LSWT - Tunnel Internals: Bid & Let Contracts	17w	40	14 May '98	23 Aug '99	14 Aug '98	24 Nov '99	320d
202	5400	TSWT - Tunnel Internals: Bid & Let Contracts	17w	41	14 May '98	19 Jul '99	14 Sep '98	17 Nov '99	295d
138	4610	LSWT - Model Support Sys: Install	26w	40	14 May '98	2 Jul '99	14 Sep '98	2 Nov '99	285d
52	5100	Bldgs. - Tunnel Enclosure: Construct	52w	136	14 May '98	18 Nov '99	18 Nov '98	24 May '00	380d
107	7230	TSWT - DAS: Install	17w	33.37FF 87FF+13w	14 May '98	12 Sep '00	26 May '99	24 Sep '01	585d
118	7220	LSWT - DAS: Install	17w	104	12 Jun '98	9 Feb '00	13 Oct '98	8 Jun '00	415d
83	2000	Bldgs. - Support & Utility Bldgs.: Construct	65w	113	12 Jun '98	24 Feb '00	13 Oct '98	22 Jun '00	425d
				33.37FF+9w 71SS+39w	20 Jul '98	25 Jun '99	2 Nov '99	16 Jan '01	235d

**NATIONAL WINN-DIXIE COMPLEX**  
Joint Industry Government Team  
Task Sheet

ID	WBS	Name	Duration	Predecessors	Early Start	Late Start	Early Finish	Late Finish	Total Slack
241	3A10	NWTC - Aux. Systems Productivity Items: Install	8w	240	17 Aug '98	1 Nov '00	13 Oct '98	29 Dec '00	555d
245	4660	LSWT - Ground Planes: Install	8w	244	17 Aug '98	16 Nov '00	13 Oct '98	16 Jan '01	565d
250	7000	NWTC - Operations Equip. & Instruments: Install	8w	249	17 Aug '98	1 Nov '00	13 Oct '98	29 Dec '00	555d
108	3000	NWTC - Aux. Systems (Other): Install	39w	226	17 Aug '98	2 Feb '00	26 May '99	7 Nov '00	365d
143	54A0	TSWT - Choke System: Manufacture	40w	130	17 Aug '98	26 Nov '99	3 Jun '99	11 Sep '00	320d
173	5460	TSWT - Plenum Evacuation Sys: Install	52w	222	17 Aug '98	27 Oct '99	27 Aug '99	7 Nov '00	300d
176	3400	NWTC - Cooling Water Plant: Install	52w	225	17 Aug '98	18 Feb '99	27 Aug '99	1 Mar '00	125d
105	7720	LSWT - C&I: Manufacture	56w	102	17 Aug '98	6 Oct '98	27 Sep '99	17 Nov '99	35d
110	7730	TSWT - C&I: Manufacture	78w	223	17 Aug '98	18 Dec '98	8 Mar '00	7 Jul '00	85d
174	3620	NWTC - HP Air Plant: Install	78w	224	17 Aug '98	14 Oct '98	8 Mar '00	3 May '00	40d
175	3200	NWTC - Tunnel Pressurization Plant: Install	6w	69 59	31 Aug '98	16 Aug '99	13 Oct '98	27 Sep '99	240d
197	4400	LSWT - Compressor: Shipping to Site	26w	186	15 Sep '98	18 Nov '99	24 Mar '99	24 May '00	295d
203	5400	TSWT - Tunnel Internals: Manufacture	26w	202	15 Sep '98	3 Nov '99	24 Mar '99	10 May '00	285d
89	5700	TSWT - Compressor: Receive on Site	0w	80	13 Oct '98	27 Sep '99	13 Oct '98	27 Sep '99	240d
242	3A10	NWTC - Aux. Systems Productivity Items: Checkout	2w	241	14 Oct '98	2 Jan '01	27 Oct '98	16 Jan '01	555d
246	4660	LSWT - Ground Planes: Checkout	2w	245	14 Oct '98	17 Jan '01	27 Oct '98	30 Jan '01	565d
251	7000	NWTC - Operations Equip. & Instruments: Checkout	2w	250	14 Oct '98	2 Jan '01	27 Oct '98	16 Jan '01	555d
109	7230	TSWT - DAS: Checkout	17w	107	14 Oct '98	9 Jun '00	17 Feb '99	10 Oct '00	415d
119	7220	LSWT - DAS: Checkout	17w	118	14 Oct '98	23 Jun '00	17 Feb '99	24 Oct '00	425d
77	5300	TSWT - Isolation Valves: Checkout	8w	78	21 Oct '98	13 May '99	17 Dec '98	9 Oct '99	140d
45	4100	Bldgs - Tunnel Enclosure: Construct	52w	33,37FF+9w,86FF+13w	19 Nov '98	26 Sep '00	2 Dec '99	9 Oct '01	465d
148	5480	TSWT - Flex Nozzle: Receive on Site	4w	144	18 Dec '98	16 Jun '00	19 Jan '99	14 Jul '00	375d
233	5A10	TSWT - Productivity Items: Install / Accept	8w	232	18 Dec '98	1 Nov '00	17 Feb '99	29 Dec '00	470d
237	4A10	LSWT - Productivity Items: Install	8w	236	18 Dec '98	16 Nov '00	17 Feb '99	16 Jan '01	480d
87	5230	TSWT - Pressure Shell: Conduct Hydrostatic Test	9w	77,78,228	18 Dec '98	12 Jul '99	24 Feb '99	13 Sep '99	140d
186	4680	LSWT - External Balances: Shipping to Site	4w	185	20 Jan '99	27 Dec '99	17 Feb '99	25 Jan '00	235d
187	4680	LSWT - External Balances: Receive on Site	0w	186	17 Feb '99	25 Jan '00	17 Feb '99	25 Jan '00	235d
234	5A10	TSWT - Productivity Items: Checkout	2w	233	18 Feb '99	2 Jan '01	3 Mar '99	16 Jan '01	470d
238	4A10	LSWT - Productivity Items: Checkout	2w	237	18 Feb '99	17 Jan '01	3 Mar '99	30 Jan '01	480d
172	5440	TSWT - Heat Exchanger: Install	13w	171,87	25 Feb '99	9 Jun '00	26 May '99	11 Sep '00	325d
164	5480	TSWT - Flex Nozzle: Install	16w	148,87	25 Feb '99	17 Jul '00	17 Jun '99	7 Nov '00	350d
137	5610	TSWT - Model Support Sys: Install	26w	127,87	25 Feb '99	10 Nov '99	27 Aug '99	17 May '00	180d
123	3810	TSWT - Electrical System: Install	30w	115,87	25 Feb '99	14 Sep '99	27 Sep '99	19 Apr '00	140d
94	5700	TSWT - Compressor: Install	39w	89,87	25 Feb '99	28 Sep '99	2 Dec '99	7 Jul '00	150d
198	4400	LSWT - Tunnel Internals: Shipping to Site	4w	197	25 Mar '99	25 May '00	21 Apr '99	22 Jun '00	295d
204	5400	TSWT - Tunnel Internals: Shipping to Site	0w	203	25 Mar '99	11 May '00	21 Apr '99	8 Jun '00	285d
199	4400	LSWT - Tunnel Internals: Receive on Site	0w	198	21 Apr '99	22 Jun '00	21 Apr '99	22 Jun '00	295d
205	5400	TSWT - Tunnel Internals: Receive on Site	0w	204	21 Apr '99	8 Jun '00	21 Apr '99	8 Jun '00	285d
200	4400	LSWT - Tunnel Internals: Install	26w	199	22 Apr '99	23 Jun '00	26 Oct '99	29 Dec '00	295d
206	5400	TSWT - Tunnel Internals: Install	26w	205	22 Apr '99	9 Jun '00	26 Oct '99	14 Dec '00	285d
76	4300	LSWT - Isolation Valves: Checkout	8w	75	29 Apr '99	29 Apr '99	24 Jun '99	24 Jun '99	0d
90	2210	Bldgs - Drive Bldg.: Construct	39w	33,37FF+9w,83SS+39w	29 Apr '99	6 Apr '00	8 Feb '00	16 Jan '01	235d
192	5650	TSWT - External Balance: Shipping to Site	4w	191	27 May '99	19 Jan '00	24 Jun '99	15 Feb '00	160d
247	3910	NWTC - Aux. Systems (Other): Checkout	9w	108	27 May '99	8 Nov '00	30 Jul '99	16 Jan '01	365d
147	54A0	TSWT - Choke System: Receive on Site	4w	143	4 Jun '99	12 Sep '00	1 Jul '99	10 Oct '00	320d
153	5480	TSWT - Flex Nozzle: Checkout	9w	164	18 Jun '99	8 Nov '00	20 Aug '99	16 Jan '01	350d
91	4570	LSWT - Test Sect. & Carts: Shipping to Site	10w	72,71SS+43w,41FF+65w	18 Jun '99	18 Jun '99	27 Aug '99	27 Aug '99	0d
95	5510	TSWT - Test Sect. & Carts: Shipping to Site	10w	81,82SS+43w,40FF+65w	18 Jun '99	12 Jul '99	27 Aug '99	20 Sep '99	15d
193	5650	TSWT - External Balance: Receive on Site	0w	192	24 Jun '99	15 Feb '00	24 Jun '99	15 Feb '00	160d
86	4230	LSWT - Pressure Shell: Conduct Hydrostatic Test	9w	76,75,227	25 Jun '99	25 Jun '99	27 Aug '99	27 Aug '99	0d
163	54A0	TSWT - Choke System: Install	9w	147,87	2 Jul '99	11 Oct '00	3 Sep '99	14 Dec '00	320d
168	4440	LSWT - Heat Exchanger: Install	8w	167,66	30 Aug '99	31 Jul '00	26 Oct '99	25 Sep '00	230d

# NATIONAL WIND TUNNEL COMPLEX

Joint Industry Government Team

## Task Sheet

ID	WBS	Name	Duration	Predecessors	Early Start	Late Start	Early Finish	Late Finish	Total Slack
181	3400	NWTC - Cooling Water Plant: Checkout	9w	176	30 Aug '99	2 Mar '00	2 Nov '99	3 May '00	125d
96	5510	TSWT - Test Sect. & Carts: Install	20w	95,87	30 Aug '99	21 Sep '99	25 Jan '00	15 Feb '00	15d
97	4570	LSWT - Test Sect. & Carts: Install	20w	86,91	30 Aug '99	25 Jan '00	25 Jan '00	25 Jan '00	0d
92	4700	LSWT - Compressor: Install	26w	84,86	30 Aug '99	20 Apr '00	8 Mar '00	24 Oct '00	160d
116	3810	LSWT - Electrical System: Install	30w	111,86	30 Aug '99	21 Sep '99	5 Apr '00	26 Apr '00	15d
152	5440	TSWT - Choke System: Checkout	4w	163	7 Sep '99	15 Dec '00	4 Oct '99	16 Jan '01	320d
112	7730	TSWT - C&I: Receive on Site	4w	105	28 Sep '99	18 Nov '99	26 Oct '99	16 Dec '99	35d
122	7730	TSWT - C&I: Receive on Site	4w	110	28 Sep '99	3 Nov '99	26 Oct '99	2 Dec '99	25d
129	3810	TSWT - Electrical Systems: Checkout	4w	123	28 Sep '99	20 Apr '00	26 Oct '99	17 May '00	140d
201	4400	LSWT - Tunnel Internals: Inspect / Accept	4w	200	27 Oct '99	2 Jan '01	24 Nov '99	30 Jan '01	295d
207	5400	TSWT - Tunnel Internals: Inspect / Accept	4w	206	27 Oct '99	15 Dec '99	24 Nov '99	16 Jan '01	285d
117	7720	LSWT - C&I: Install	26w	112,86	27 Oct '99	17 Dec '99	3 May '00	22 Jun '01	35d
128	7730	TSWT - C&I: Install	26w	122,87	27 Oct '99	3 Dec '99	3 May '00	8 Jun '00	25d
141	3400	TSWT - Cooling System: Checkout	4w	172,129,181	3 Nov '99	12 Sep '00	2 Dec '99	10 Oct '00	215d
151	5460	TSWT - Plenum Evacuation Sys: Checkout	9w	173,181	3 Nov '99	8 Nov '00	10 Jan '00	16 Jan '01	255d
99	5700	TSWT - Compressor & Drive Sys: Checkout	26w	94,216	3 Dec '99	10 Jul '00	8 Jun '00	16 Jan '01	150d
194	5650	TSWT - External Balance: Install	9w	193,96	26 Jan '00	16 Feb '00	29 Mar '00	19 Apr '00	15d
188	4680	LSWT - External Balances: Install	13w	187,97	26 Jan '00	26 Jan '00	26 Apr '00	26 Apr '00	0d
180	3200	NWTC - Tunnel Pressurization Plant: Checkout	9w	175,181	9 Mar '00	4 May '00	10 May '00	7 Jul '00	40d
98	4700	LSWT - Compressor & Drive Sys: Checkout	13w	92,221,90SS+17w	9 Mar '00	25 Oct '00	8 Jun '00	30 Jan '01	160d
195	5650	TSWT - External Balance: Checkout	4w	194	30 Mar '00	20 Apr '00	26 Apr '00	17 May '00	15d
124	3810	LSWT - Electrical System: Checkout	4w	116	6 Apr '00	27 Apr '00	3 May '00	24 May '00	15d
189	4680	LSWT - External Balances: Checkout	4w	188	27 Apr '00	27 Apr '00	24 May '00	24 May '00	0d
139	5510	TSWT - Test Sect. & Carts: Checkout	9w	129,195,96,108SS	27 Apr '00	18 May '00	29 Jun '00	10 Oct '00	15d
146	5610	TSWT - Model Support Sys: Checkout	20w	137,139SS	27 Apr '00	18 May '00	18 Sep '00	10 Oct '00	15d
134	3400	LSWT - Cooling System: Checkout	4w	168,124,181	4 May '00	26 Sep '00	1 Jun '00	24 Oct '00	100d
125	7720	LSWT - C&I: Checkout	17w	117	4 May '00	23 Jun '00	1 Sep '00	24 Oct '00	35d
252	7730	TSWT - C&I: Checkout	17w	128	4 May '00	9 Jun '00	1 Sep '00	10 Oct '00	25d
133	3200	LSWT - Tunnel Pressurization Sys: Checkout	9w	124,180	11 May '00	21 Aug '00	14 Jul '00	24 Oct '00	70d
140	3200	TSWT - Tunnel Pressurization Sys: Checkout	9w	129,180	11 May '00	7 Aug '00	14 Jul '00	10 Oct '00	60d
179	3620	NWTC - HP Air Plant: Checkout	9w	174,180	11 May '00	10 Jul '00	14 Jul '00	11 Sep '00	40d
135	4570	LSWT - Test Sect. & Carts: Checkout	9w	124,189,97,108SS	25 May '00	25 May '00	28 Jul '00	24 Oct '00	0d
145	4610	LSWT - Model Support Sys: Checkout	21w	138,135SS	25 May '00	25 May '00	24 Oct '00	24 Oct '00	0d
132	3620	LSWT - HP Air System: Checkout	4w	124,179	17 Jul '00	26 Sep '00	11 Aug '00	24 Oct '00	50d
142	3620	TSWT - HP Air System: Checkout	4w	129,179	17 Jul '00	12 Sep '00	11 Aug '00	10 Oct '00	40d
150	7700	TSWT - C&I / DAS: Integrated Systems Checkout	13w	109,146,252,139,140,141,142	19 Sep '00	11 Oct '00	21 Dec '00	16 Jan '01	15d
149	7720	LSWT - C&I / DAS: Integrated Systems Checkout	13w	125,145,119,132,133,134,135	25 Oct '00	25 Oct '00	30 Jan '01	30 Jan '01	0d
155	5910	TSWT - Integrated Tunnel Systems: Checkout	35w	150,151,152,153,207,83,90,234,242,247,251	22 Dec '00	17 Jan '01	31 Aug '01	24 Sep '01	15d
157	5910	TSWT - Integrated Tunnel Systems: Conduct Post-Checkout Repairs	35w	155SS,52FF,82FF	22 Dec '00	17 Jan '01	31 Aug '01	24 Sep '01	15d
154	4910	LSWT - Integrated Tunnel Systems: Checkout	35w	98,149,201,83,90,238,242,246,247,251	31 Jan '01	31 Jan '01	9 Oct '01	9 Oct '01	0d
156	4910	LSWT - Integrated Tunnel Systems: Checkout	35w	154SS,45FF,71FF	31 Jan '01	31 Jan '01	9 Oct '01	9 Oct '01	0d
159	5920	TSWT - Calibration	26w	157,155	4 Sep '01	25 Sep '01	13 Mar '02	3 Apr '02	15d
158	4920	LSWT - Calibration	24w	156,154	10 Oct '01	10 Oct '01	3 Apr '02	3 Apr '02	0d
161	8300	TSWT - Ready to Test Models	0w	159	13 Mar '02	3 Apr '02	13 Mar '02	3 Apr '02	15d
160	8300	NWTC - Ready to Test Models	0w	158	3 Apr '02	3 Apr '02	3 Apr '02	3 Apr '02	0d
162	8000	NWTC - Project Complete	0w	160,161,39,45,52,71,82,83,90,253	3 Apr '02	3 Apr '02	3 Apr '02	3 Apr '02	0d

**National Wind Tunnel Complex**  
**Joint Industry Government Team**

**Appendix 5**

**Concept D - Option 5**

**Studies Listing**

1

2

3

# ENGINEERING STUDIES FOR NATIONAL WIND TUNNELS

1-Mar-94

No.	Order	Description	GA Team Disposition	Priority	Support	Potential Agency	Cost (\$K)	URGENT #1	URGENT #2	Design Verifica	POD
A	0.0	Requirements frozen	Project Office Issue	1	concept	Task group					
57	1.0	Acquisition Strategy	Project Office Issue	1		FSO					
B	2.0	Requirements Doc.	Project Office Issue	1	concept	FSO/Task Group					
58	3.0	WBS Review	Project Office Issue	1		FSO					
59	4.0	Design Criteria	Consortium Issue	1		FSO					
62	4.1	System Engineering Plan	Consortium Issue	1	PER	FSO	80		80		
64	4.2	Assess Current Design Tools	Consortium Issue	3	PER	Contractor	10		10		
5	5.0	External balance load path, envelop, anchor point	URGENT	1	concept	Sverdrup/FluidDyne	100	100			
6	6.0	Isolation valves	URGENT	1	PER	Sverdrup or FluidDyne	225	225			
43	7.0	LSWT open jet aero perf. study	URGENT*	2	PER/pilot studies	Vigyan	210	60	150		
49	8.0	TSWT Choke & re-entry	URGENT for 10.0	1	PER	SW/FluidDyne	250	250			
35	9.0	Wall interference study (may influence req'tments)	URGENT	1	concept	AEDC	45	45			
65	10.0	Cart/Test Section/Model Support Integration	URGENT/POD	1	PER	Sverdrup/FluidDyne					
9	10.1	Model support system/roll drive	URGENT/POD	1	PER	Sverdrup/FluidDyne	1080	180			900
10	10.2	Test bed cart concept dev, productivity, integration	URGENT/POD	1	PER	Sverdrup/FluidDyne	1350	100			1250
12	10.3	Model access	URGENT/POD	1	PER	Sverdrup/FluidDyne	60	20			40
18	10.4	Req'd tolerances /alignment of carts/test section	POD - Part of Design	2	PER	Sverdrup	40				40
21	10.5	Hot jet propulsion testing in LSWT	POD	2	PER	Sverdrup/FluidDyne	30				30
29	11.0	TSWT/LSWT aero lines & aux. systems	URGENT	1	concept	Sverdrup/FluidDyne	425	425			
30	11.1	Contraction/honeycomb/screen, study-both tun.	URGENT	1	pre concept	LaRC, ARC, AEDC	0				
33	11.2	LSWT Cooler study, aero., heat trans., position	URGENT	1	PER	Sverdrup or FluidDyne	50	50			
34	11.3	TSWT cooler study, aero., heat trans., position	URGENT	1	PER	Sverdrup or FluidDyne	50	50			
69	11.4	TSWT Acoustic Cart Concept Study	URGENT	1	PER	Contractor	75	75			
45	11.5	Tunnel circuit acoustical study for both tunnels	URGENT	2	part of PER	John Wilby (SW/AR)	200	200			
61	12.0	Shel Pressure Test - Pneumatic Risk analysis	URGENT	1	PER	NNSY/Navy/Douglas	250		250		
53	13.0	Knowledge management & system integration	Urgent Owner Study	1	concept/PER	Sverdrup	10		10		
51	13.1	Establish design/data library of existing data	Urgent Owner Study	1		Sverdrup	10		10		
63	13.2	Knowledge Management Plan	Urgent Owner Study	1		Sverdrup	10		10		
44	14.0	LSWT open jet verification test	Urgent Dsgn Verification	2	final design	Agency @ PPO	200	200			
36	15.1	Establish wall to minimize interference, TSWT	Gov't Research	1	final design	AEDC 1T	850			850	
37	15.2	Establish wall to minimize interference, LSWT	Gov't Research	1	final design	LaRC or AEDC 1T	650			650	
55	15.3	8/day yr test for semispan/gmd effect testing	Gov't Research	2	PER	LaRC/NITF	40			40	
48	16.0	Honeycomb/screens, verification-both tun	Urgent Dsgn Verification	3	final design	AEDC	50		50		
42	17.0	CFD model of TSWT high speed leg	Design Verification	2	PER/pilot studies	AEDC	200			200	
8	18.0	Time and motion study of complex	Design Verification	1	final design	Sverdrup or FluidDyne	100			100	
60	18.1	Productivity/Time and Motion	Design Verification	1	final design	Sverdrup or FluidDyne	70			70	
41	19.0	LSWT/TSWT heat exchanger aero verification	Design Verification	2	final design	LaRC/BART or univer	250			250	
26	20.0	TSWT pilot tunnel procurement	Design Verification	1	PER/final design	ARC or AEDC	3000			3000	
56	21.0	Turning vane - fluid & acoustical performance	Design Verification	2	final design	ARC/AEDC/LaRC	200			200	
28	22.0	TSWT pilot tunnel verification tests (tunnel ops.)	Design Verification	1	PER/final design	ARC or AEDC	350			350	
39	23.0	TSWT high speed leg integration tests	Design Verification	1	PER/final design	ARC or AEDC	250			250	
13	24.0	Environmental Assessment	MOVE WBS 1000	1	PER	EBASCO					
2	25.0	TSWT dynamic model	POD	1	PER	Vigyan	30				30
1	26.0	LSWT dynamic model	POD	1	PER	Vigyan	30				30
4	27.0	Productivity studies, LSWT and TSWT	POD	1	concept	Sverdrup	0				30
31	28.0	Fan design study TSWT	POD	1	PER	ARC/AEDC	0				

# ENGINEERING STUDIES FOR NATIONAL WIND TUNNELS

1-Mar-94

No.	Order	Description	GA Team Disposition	Priority	Support	Potential Agency	Cost (\$K)	URGENT #1	URGENT #2	Dsgn Verifica	POD
32	29.0	Fan design study LSWT	POD	1	PER	ARC/AEDC	0				
17	30.0	Constructability of large components	POD	2	PER	CB&I etc	20				20
66	31.0	Drive System Conceptual Design	POD	1	PER	Contractor	250				250
3	32.0	Aux. systems dynamic model	POD	1	PER	Vigyan	50				50
38	33.0	Internal balance stiffness	POD	1	concept	Modern Machine, etc.	100				100
40	34.0	PES acoustical suppression study	POD	1	final design	Contractor	40				40
52	35.0	LSWT/TSWT Mach control strategy & validation	POD	1	PER	SW/Flukdyne	20				20
68	36.0	Tunnel Cleaning System - Conceptual Design	POD	2	PER	SW/Flukdyne	30				30
19	37.0	Model support system math model	POD	2	PER	Part of PER	20				20
16	38.0	Data error analysis	POD	2	PER	AEDC/ARC	150				150
7	39.0	Subscale compressor for TSWT	POD	1	final design	Part of compr design					
23	43.0	Subscale compressor for LSWT	POD	3	final design	Part of compr design					
						TOTAL		1780	770	6110	2850

\*Add Scope to examine other alternatives

NOTE: Order 10 & 11 Intended to be concurrent

TOTAL GOVT PROCUREMENT  
TOTAL CONSORTIUM PROCUF

11510 Note: Gov't procurement assumes  
8660 POD moves back to studies  
because of contracting time lag

**National Wind Tunnel Complex**  
**Joint Industry Government Team**  
**Appendix 6**  
**The Boeing Company**  
**Proposed Consortium Model**



**INDUSTRY - GOVERNMENT  
WIND TUNNEL CONSORTIUM**



# AGENDA

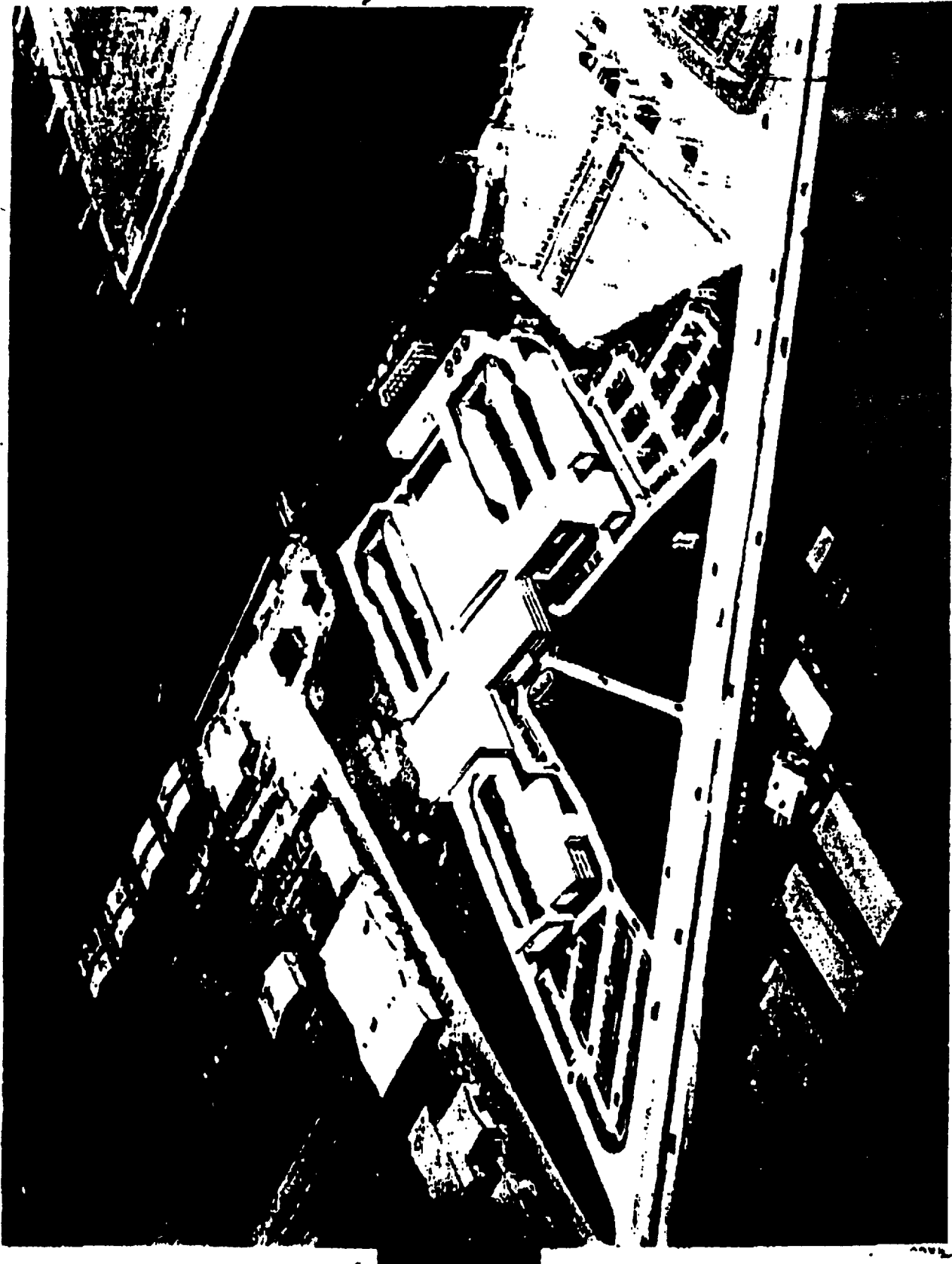
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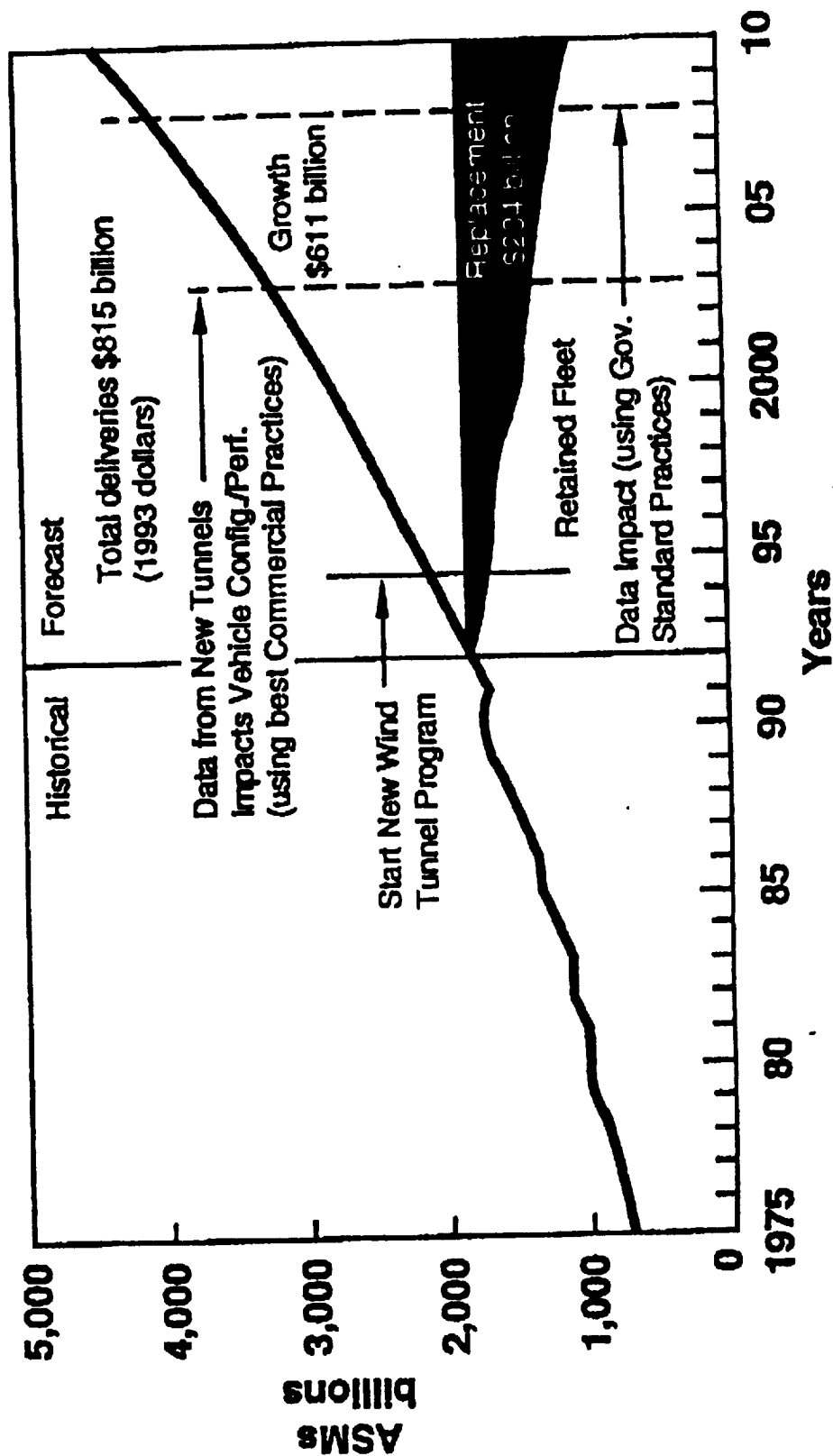
- WIND TUNNEL PROGRAM DESCRIPTION
- CONSORTIUM DESCRIPTION
- DESIGN - BUILD STRATEGY
- CONCEPT OF OPERATIONS
- ISSUES & RISKS
- ACTION PLAN

# REQUIREMENTS & OPPORTUNITY

- NATIONAL REQUIREMENTS – BETTER THAN THE COMPETITION
  - DATA FACTORY FOR U. S. AIRCRAFT DEVELOPMENT
    - BETTER DATA – BETTER DESIGNS
      - FLOW QUALITY
      - NEAR FLIGHT REYNOLDS NUMBER
      - LOWER COST TEST PROGRAM
      - SHORTER DEVELOPMENT TIME
      - PROTECT INFORMATION FROM COMPETITORS
    - USE WITH TODAY'S BEST FACILITIES
  - CAN INFLUENCE \$300B COMM. MARKET (5 YEAR SCHEDULE)

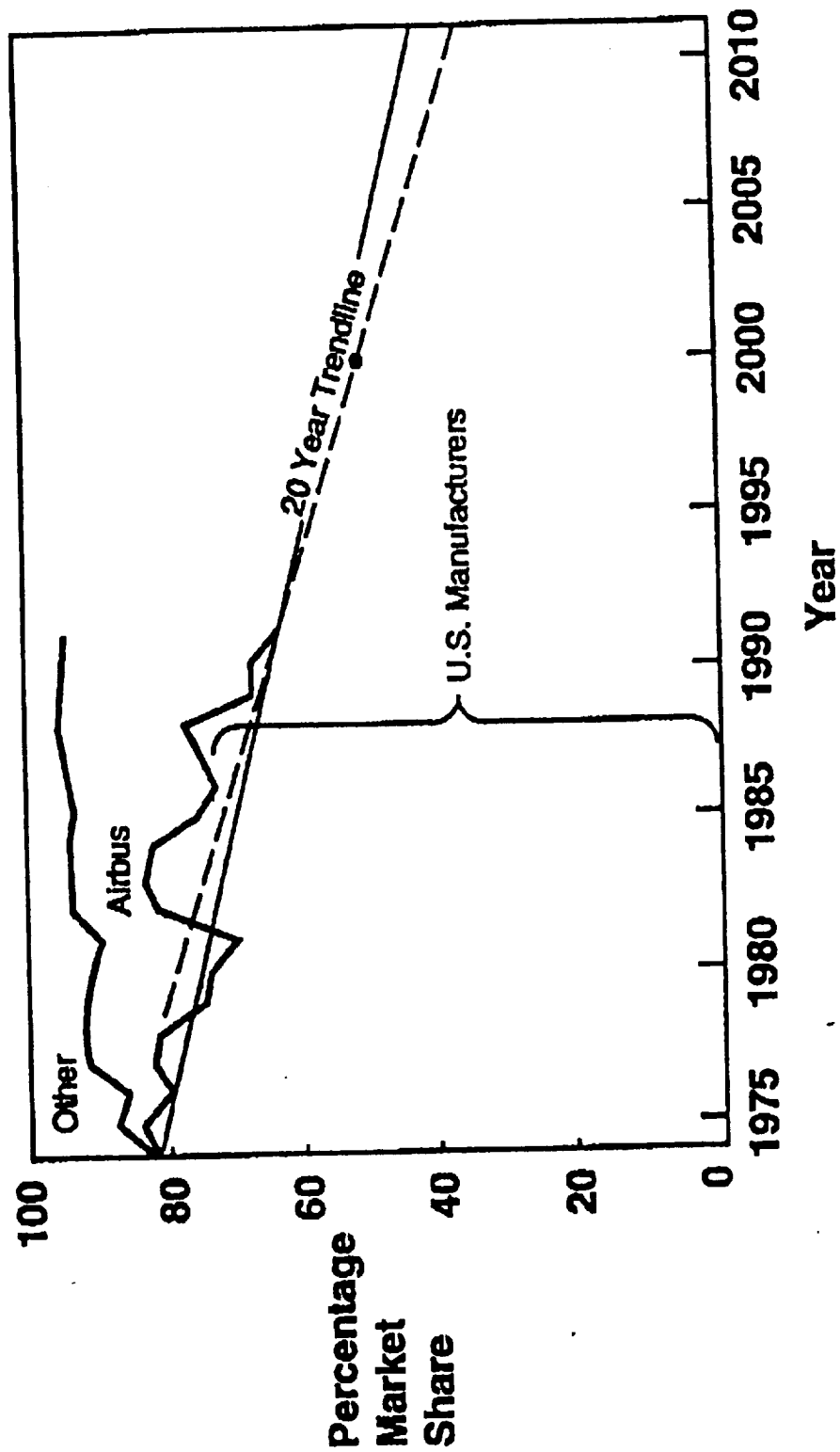


# World Capacity Requirement



World Capacity Requirement  
31 January 1994

# Market Share Commercial Airplane Orders – 1992 Dollars



Market Share-Int  
31 January 1994

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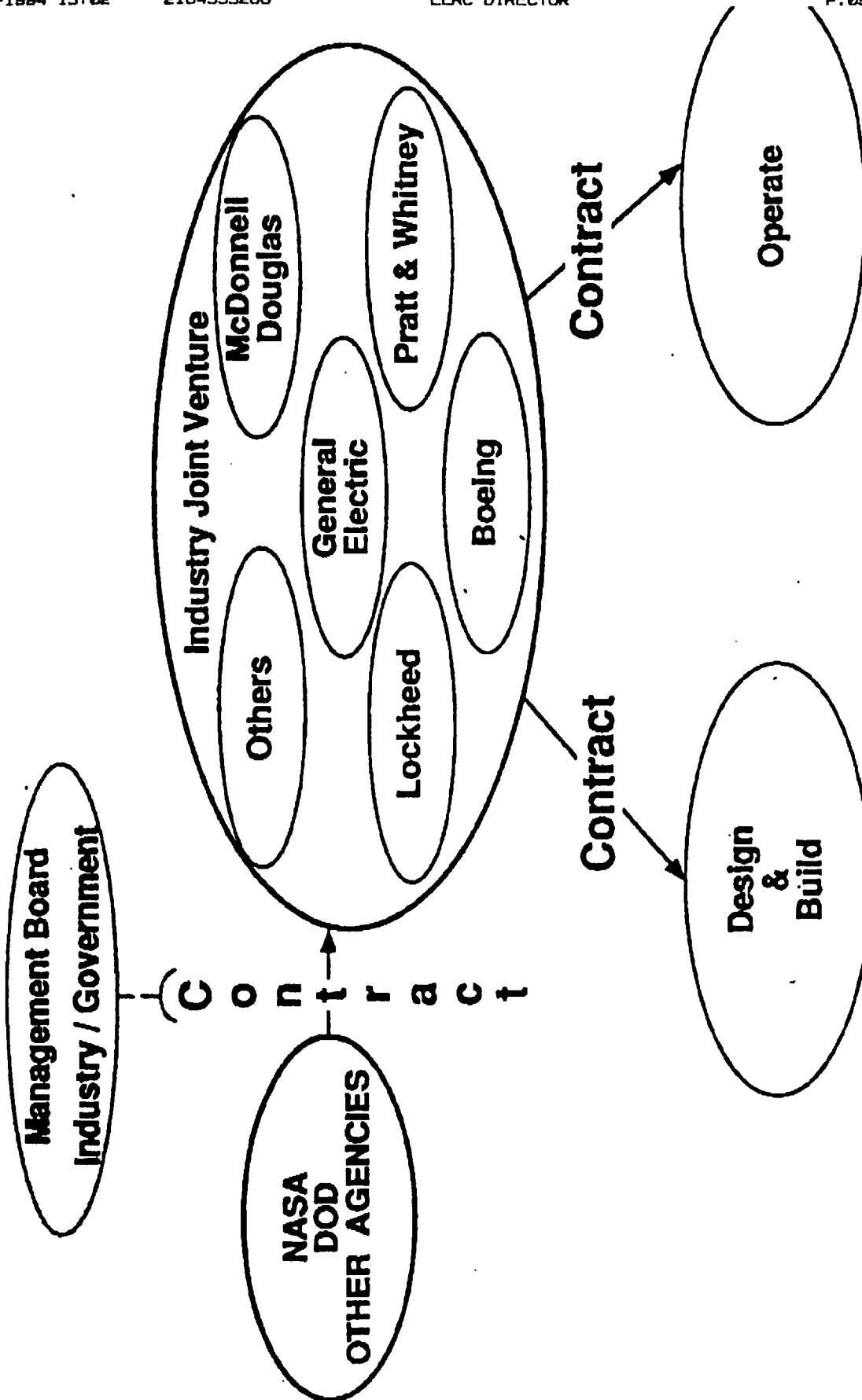
# CHARTER

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## DESIGN, SITE, BUILD AND OPERATE WIND TUNNELS FOR USE BY INDUSTRY AND GOVERNMENT TO DEVELOP ADVANCED AIRCRAFT

# PROPOSED CONSORTIUM FORMAT



# **GOVERNMENT-JOINT VENTURE CONTRACT**

- ESTABLISHES "WORKING TOGETHER" RELATIONSHIP BETWEEN GOVERNMENT AND INDUSTRY
  - SETS RIGHTS AND RESPONSIBILITIES OF CONSORTIUM MEMBERS
- JOINT VENTURE DESIGNS & BUILDS ON COST REIMBURSABLE BASIS
- GOVERNMENT OWNS WIND TUNNEL COMPLEX
- GOVERNMENT GUARANTEES SITE RELATED COSTS EQUALS "BEST COMMERCIAL PRACTICE" (ENERGY RATES, TAXES, EIS, ETC.)
- U. S. INDUSTRY AND U. S. GOVERNMENT HAVE PRIORITY ACCESS
- JOINT VENTURE -- COMMIT TO MIN ANNUAL WIND TUNNEL USE
- MANY STANDARD PROVISIONS

# JOINT VENTURE AGREEMENT

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- **MEMBERS MANAGE WIND TUNNEL JOINT VENTURE**
  - **DESIGN**
  - **DEVELOP**
  - **OPERATE**
- **MEMBERS PROVIDE STAFF TO JOINT VENTURE**
  - **COST REIMBURSABLE BASIS**
- **MEMBERS ARE ALLOCATED WIND TUNNEL USE RIGHTS**
- **OTHER STANDARD CLAUSES**
  - **MEMBERS MAY PARTICIPATE THRU SUBSIDIARIES (TAX)**
  - **INTELLECTUAL PROPERTY RIGHTS**
  - **CHANGING MEMBERSHIP – TRANSFER USE RIGHTS**
  - **ACCOUNTING, BANKING, TAXES & INSURANCE**
  - **CROSS INDEMNITIES**

# MEMBERS CONTRIBUTE EXPERTISE

## MEMBER

## CONTRIBUTION

### GE / P&W

- COMPRESSOR AERODYNAMICS
- COMPRESSOR NOISE SIGNATURE
- CIRCUIT THERMODYNAMIC CYCLE

### DOUGLAS / LOCKHEED

- CIRCUIT AERO / FLUID DYNAMICS

### BOEING

- ACQUISITION MANAGEMENT
- PROJECT INTEGRATION

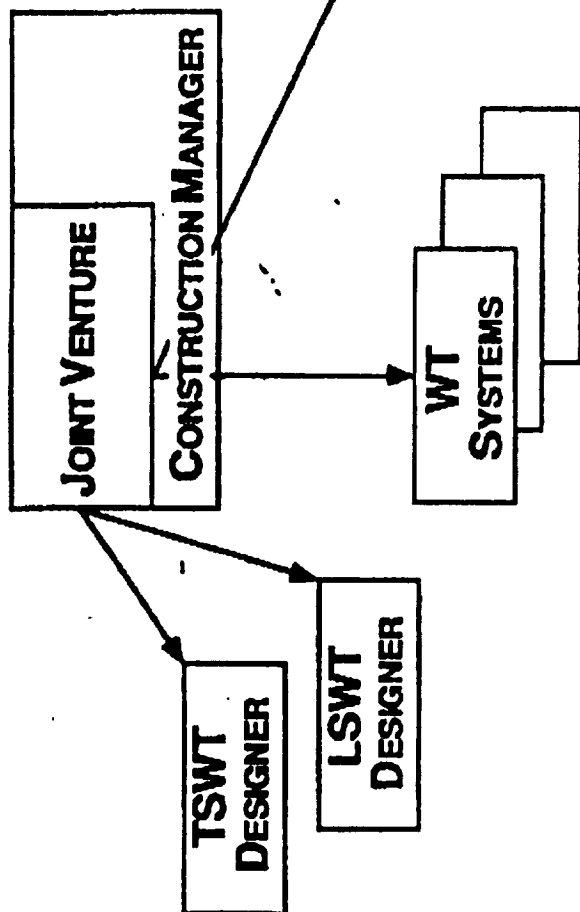
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- FACILITY TECHNICAL REQUIREMENTS
- FACILITY OPERATIONAL REQUIREMENTS

# PROPOSED CONTRACTING RELATIONSHIP

## JV/CM:

- PLANNING
- PACKAGE PREP
- SCHEDULING
- QC INSPECTION
- SAFETY
- ESTIMATING
- MAJOR INTEGRATION



## CONSTRUCTION

- BUILDINGS / SITE
- FOUNDATIONS
- BUILDING ENCLOSURE
- SITE WORK UTILITIES
- SHUTTLE CAR SYSTEM
- PRESSURE / VACUUM SYSTEMS

## DESIGN - BUILD / INSTALL

- PRESSURE VESSEL
- DRIVE MOTORS
- COMPRESSORS
- TEST SUPPORT EQUIPMENT

## DESIGNERS

- DRAWINGS
- SPECIFICATIONS
- INSTALLATION QUALITY

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1-27-94

# TESTING OPERATIONS

## • ACCESS

- .. U. S. GOVERNMENT AND U. S. INDUSTRY
  - ... CONSORTIUM - GUARANTEED MINIMUM LEVEL
  - ... NON-CONSORTIUM - PART OF MEMBER SHARE
- AS AVAILABLE BASIS

- .. FOREIGN GOVERNMENT AND FOREIGN INDUSTRY
  - ... AS AVAILABLE BASIS

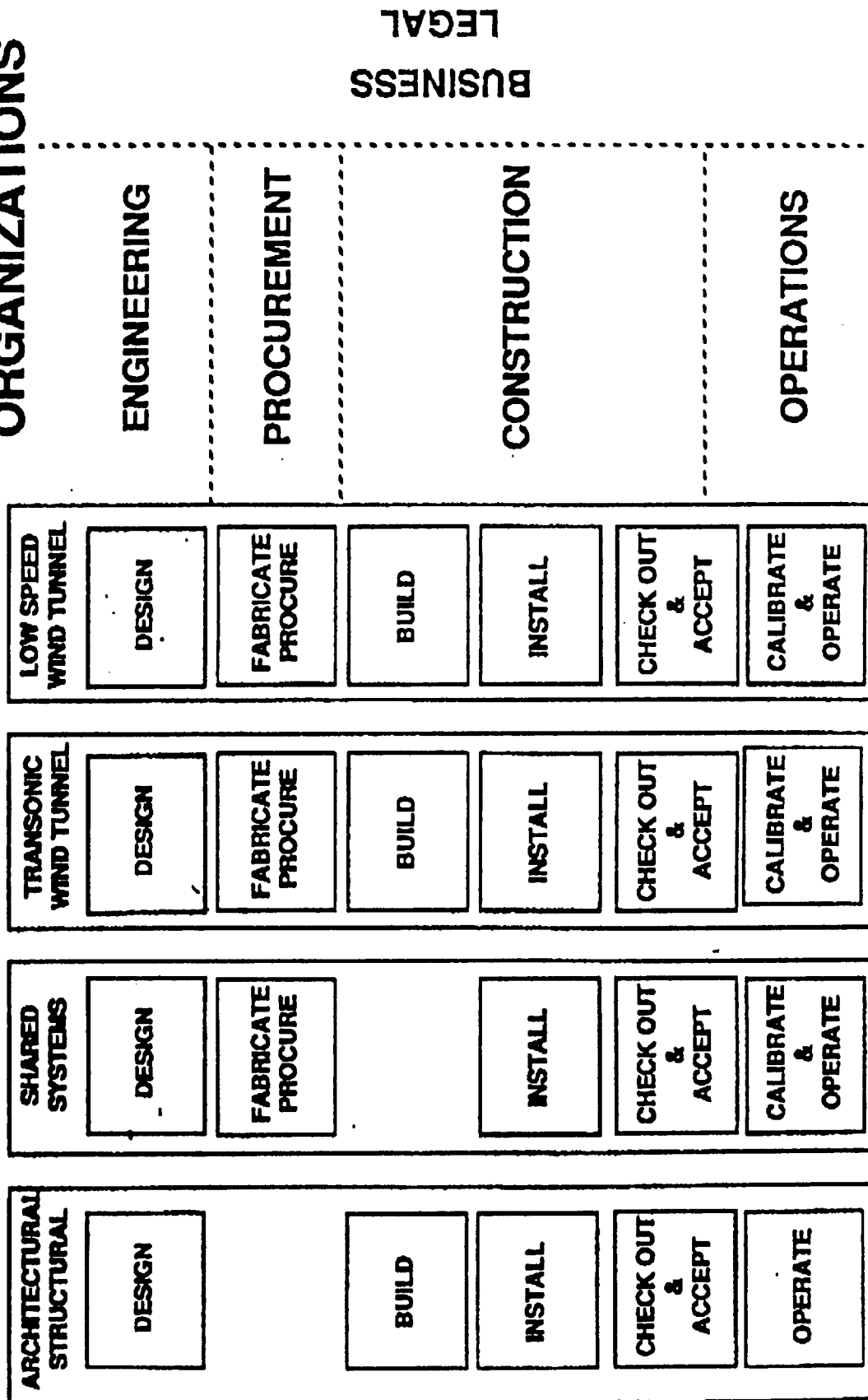
## • COST

- .. U. S. GOVERNMENT AND U. S. INDUSTRY
  - ... CONSORTIUM - OPERATING COST - SHARE OPR CAP
  - ... NON-CONSORTIUM - OPERATING COST
- .. FOREIGN GOVERNMENT AND FOREIGN INDUSTRY
  - ... PAY OPERATING COSTS
  - + PORTION OF CAPITAL COST RECOVERY
  - ... CAPITAL RECOVERY - RETURNED TO U. S. GOVERNMENT

# PROGRAM ORGANIZATION

## PROGRAM MANAGEMENT

## RESPONSIBLE ORGANIZATIONS



BUSINESS  
LEGAL

# FUNDING REQUIREMENTS

## USES

Development Capital

\$1.7 Billion

Working Capital

\$100 Million

## SOURCES

Federal Government (Dev Cap)

\$1.7 Billion

Joint Venture (Working Capital)

\$100 Million

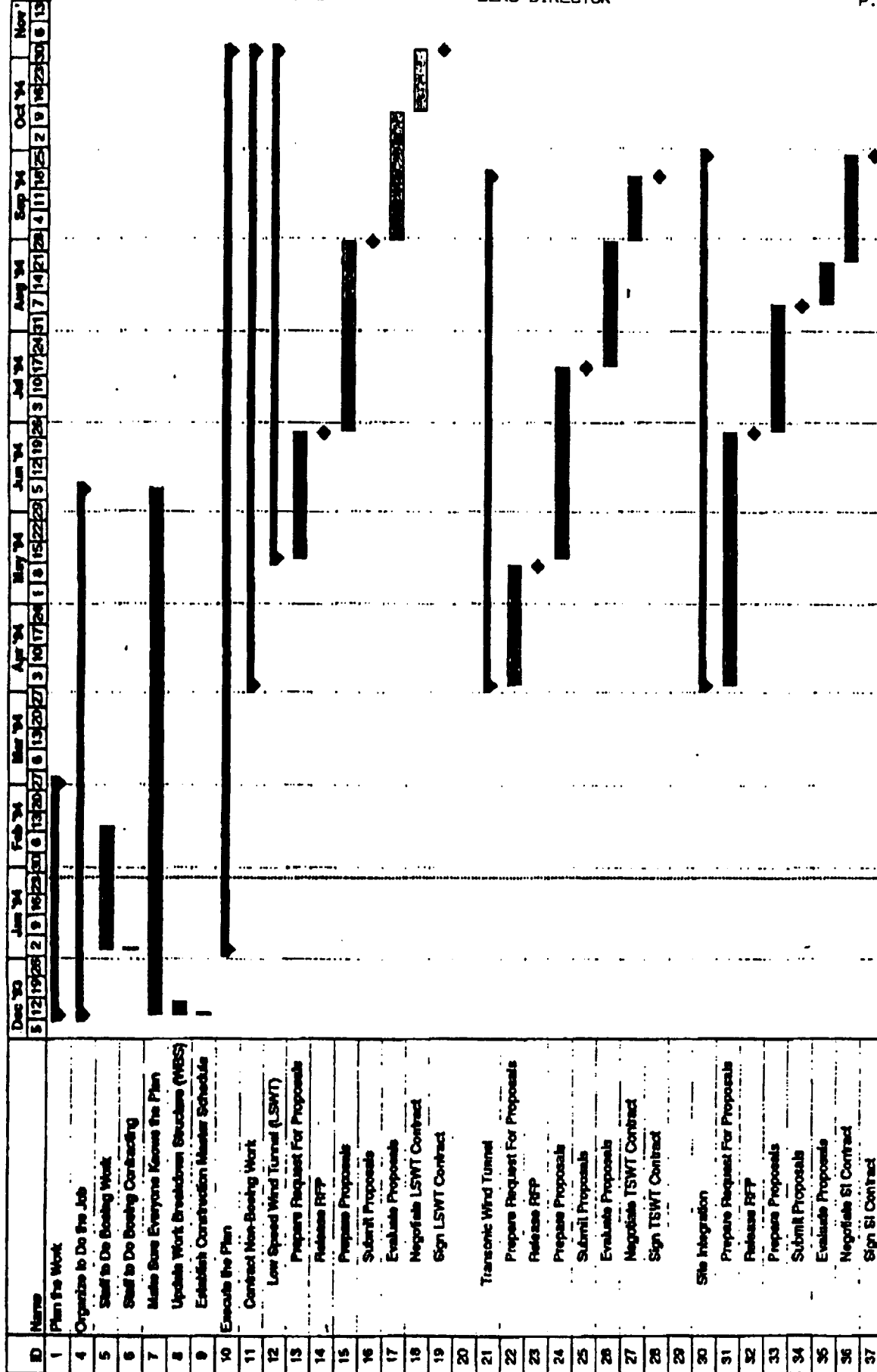
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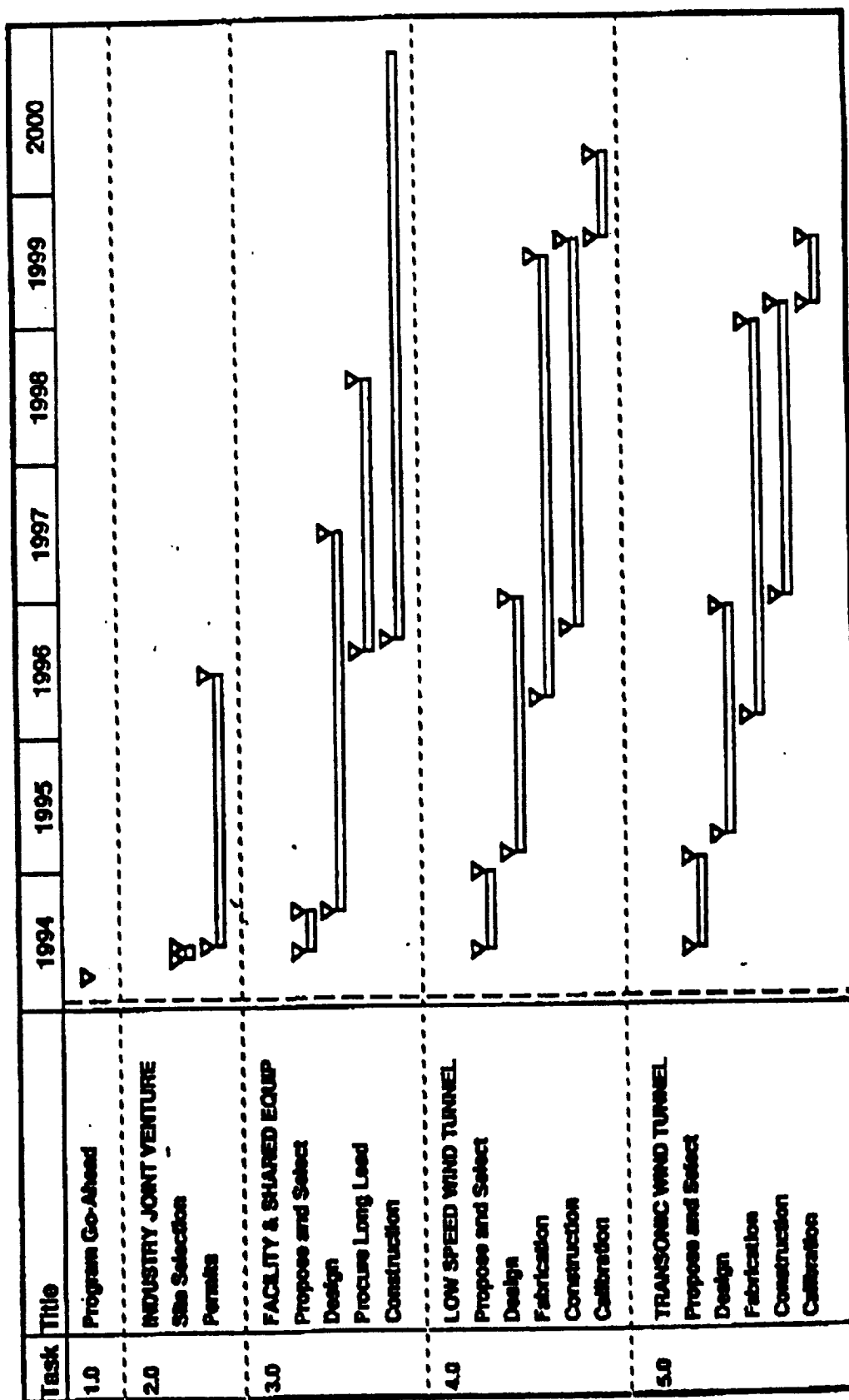
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# WIND TUNNEL PROGRAM SCHEDULE

Date:



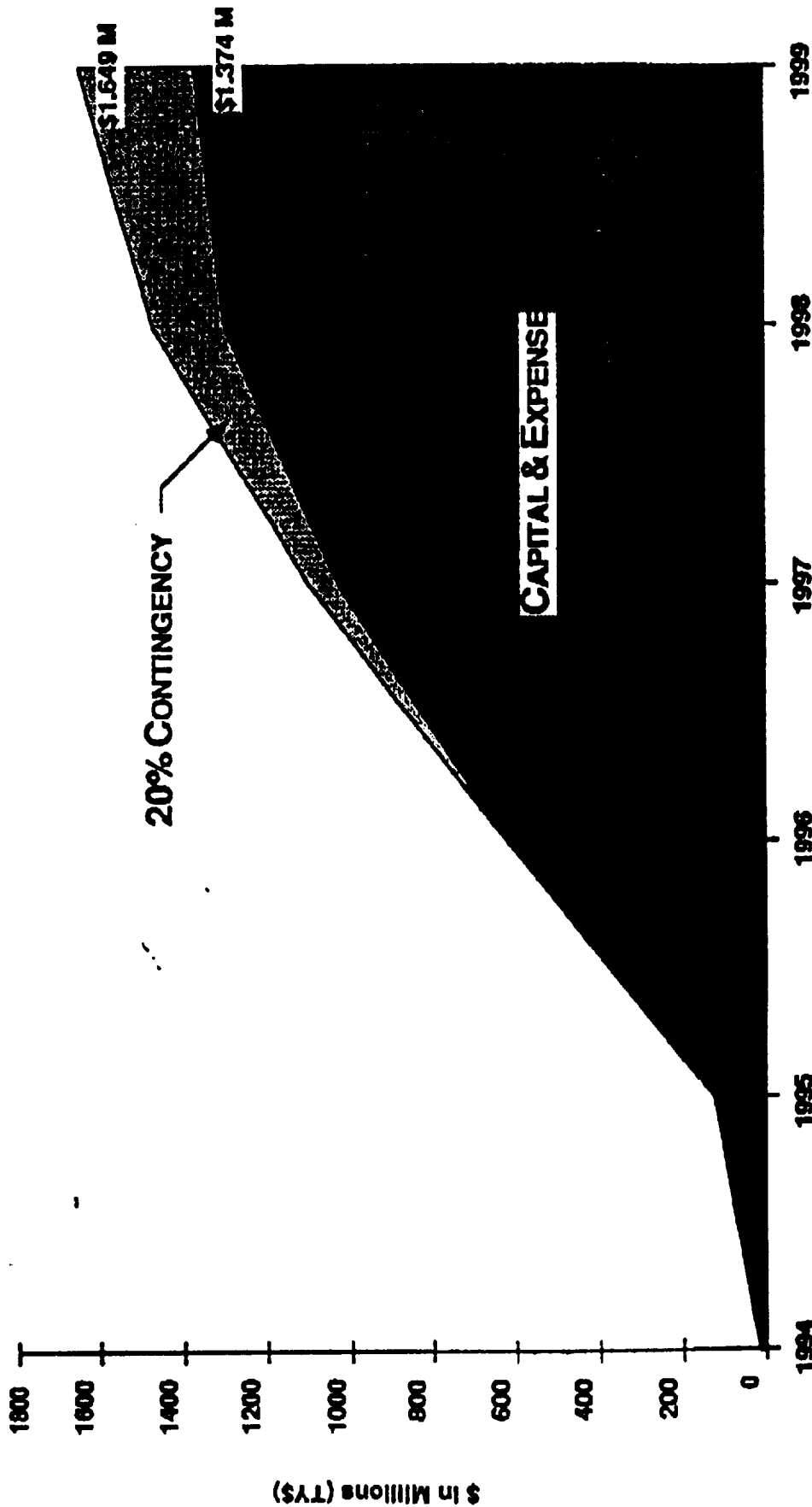
# WTC COST ESTIMATES

COST ESTIMATE SOURCE	COST (TY)	DEVELOPMENT SPAN	CONTRACT TYPE
BOEING	\$1.674 B	5 YR	CR
BECHTEL	\$1.650 B	5 YR	CR
EBASCO	\$1.664 B	5 YR	CR
NASA (A)	\$2.316 B	10 YR	FFP
NASA (D5)	>\$3. B	10 YR	FFP

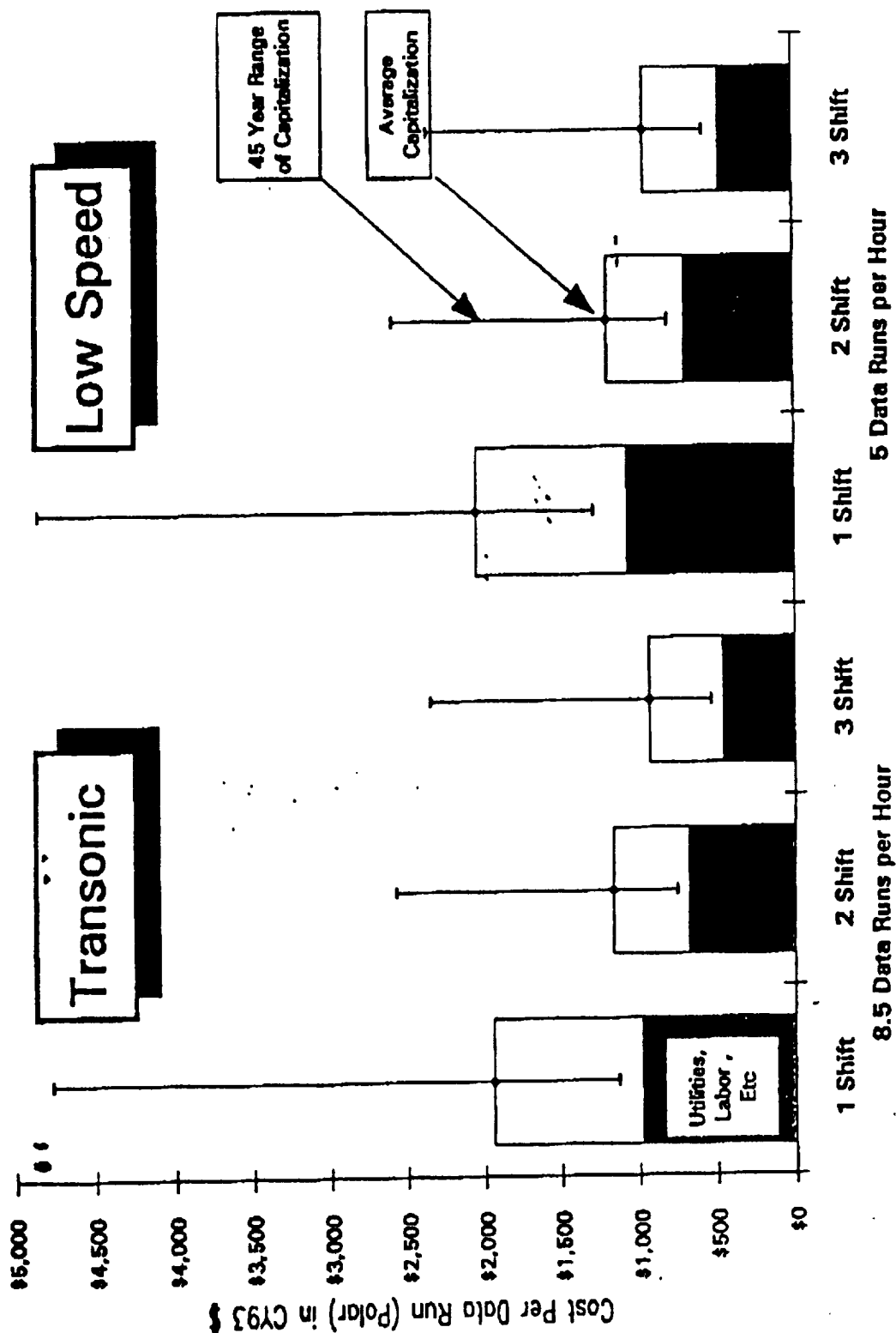
CR = Cost Reimbursable  
FFP = Firm Fixed Price

# OUTLAY PROFILE

## CUMULATIVE EXPENDITURES & COMMITMENTS

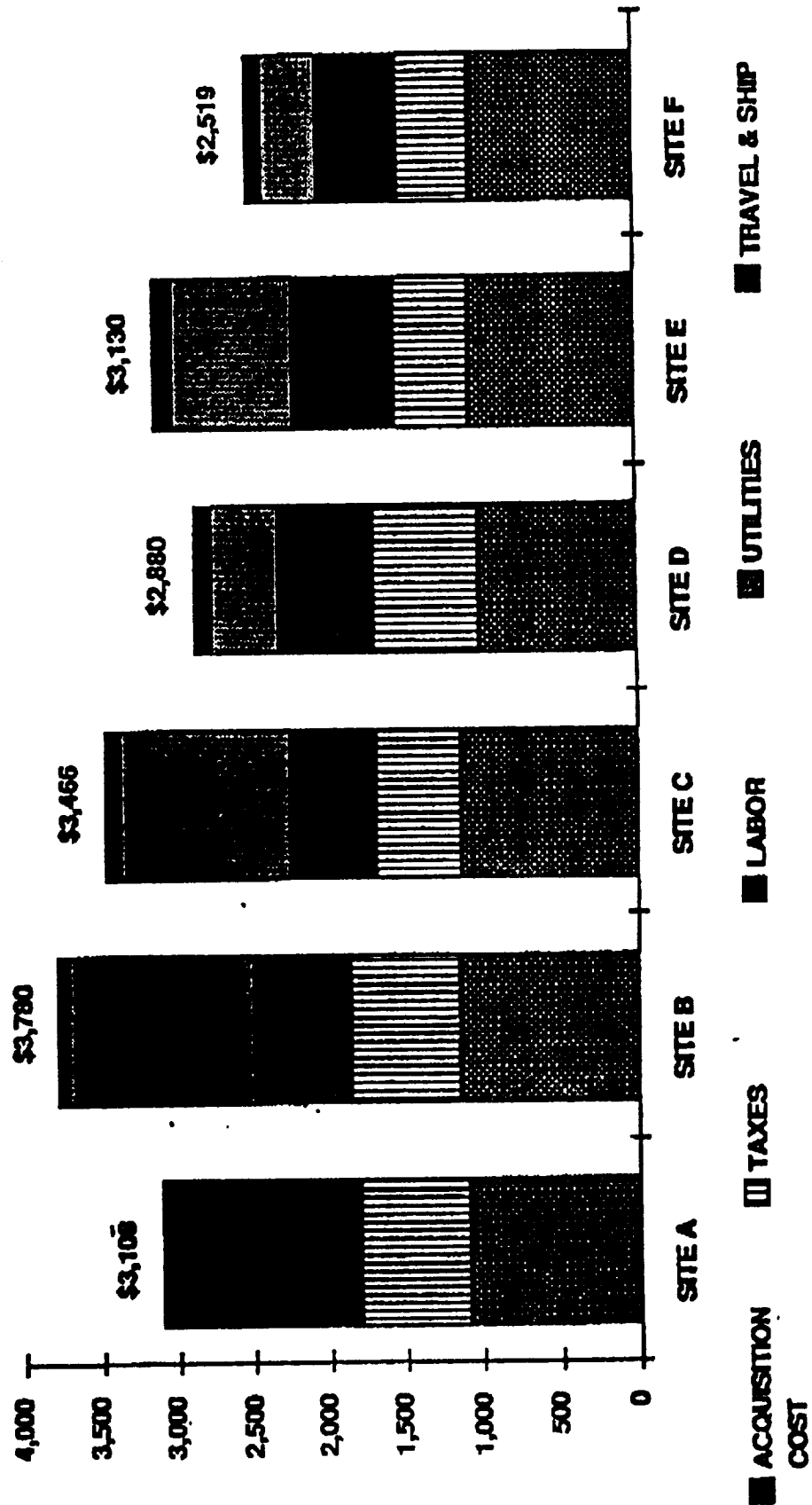


# COST PER DATA RUN



PERDRI.XLC, 1/26/94, 3:46 PM

# NWTC 45 YEAR LIFECYCLE COST



Based on \$1,394 million dollar tunnel configuration. Labor based on (2) shifts per tunnel average, 120 total heads.

# NWTC Cost Estimate Progression

(Dollars in Millions)

[REDACTED]

[REDACTED]

[REDACTED]

Increased square footage for the building and storage of additional carts.

[REDACTED]

Increased test section size.

[REDACTED]

Increased Mach Number capability, improved compressor and added variable nozzle.

[REDACTED]

Addition of two balances.

[REDACTED]

Increased Design and Management support for the additional scope.

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

NAVAL WEAPONS ADDRESS TO BUDGET

Business Management 10/1/94

# VARIATIONS FROM BASELINE

- INDUSTRY FUNDING OF SOME CAPITAL
  - OPERATING CAPITAL
  - CAPITAL FOR FACILITY
- FIXED PRICE CONTRACT
  - INCLUDE RISK CONTINGENCY
- FAR CONTRACT
  - NON-FAR IS A MUST
  - "BEST COMMERCIAL PRACTICE"
- CAPITAL COST RECOVERY

# RISKS

- SITE SELECTION
  - NOT ON SCHEDULE
  - NOT "BEST BUSINESS PRACTICE"
    - JOINT VENTURE SELECTS
    - OR, IF DICTATED, GOVERNMENT MAKES EQUAL
- CHANGING REQUIREMENTS
  - EARLY AGREEMENT
  - PERFORMANCE SPECIFICATION
- ENGINEERING CONTINUES AFTER SCHEDULED COMPLETION
  - SCHEDULED ENGINEERING TO SUPPORT
  - TECHNICAL PARTICIPANTS CONTRIBUTE, NOT REVIEW
- COST ESTIMATE LOW
  - ADEQUATE CONTINGENCY

# ACTION PLAN

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- **JOINT VENTURE MEMBERS**
  - **ESTABLISH THE JOINT VENTURE**
    - **SET UP APPROPRIATE BUSINESS UNIT**
    - **WORK TO DEVELOP JOINT VENTURE AGREEMENT**
- **JOINT VENTURE**
  - **CONTRACT WITH MEMBERS FOR THEIR SERVICES**
  - **HELP ESTABLISH "WORKING TOGETHER" CONSORTIUM**  
**CONTRACT BETWEEN GOVERNMENT & JOINT VENTURE**
  - **DEVELOP "BEST COMMERCIAL PRACTICE" APPROACH**
    - **DESIGN, BUILD, SITE, OPERATE**
    - **IMPLEMENT APPROACH**

# ACTION PLAN

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- GOVERNMENT PARTICIPANTS
  - ESTABLISH INTER-AGENCY AGREEMENTS
  - OBTAIN NON-FAR CONTRACT APPROVALS
  - HELP DEVELOP "WORKING TOGETHER" CONSORTIUM CONTRACT
  - SUPPORT FY '95 BUDGET = \$1.7 B FULLY-FUNDED ITEM
    - 5 YR OUTLAY
  - OMB RELEASE "EMBARGOED" 94 BUDGET
  - CONTRACT WITH JOINT VENTURE FOR 94 EFFORT
    - AS SOON AS FUNDS RELEASED
  - PROVIDE TECHNICAL CONTRIBUTORS
  - SUPPORT SITE SELECTION PROCESS



**National Wind Tunnel Complex**  
**Joint Industry Government Team**

**Appendix 7**

**Joint Industry Government  
Team Report to the NWTC  
Program Manager**



**Joint Industry Government Team**

**Report to**

**NWTC Program Manager**

**February 28, 1994**

# **Joint Industry Government Team**

## **Joint Industry Government Team Charter**

- Convene a joint Industry Government team at Langley Research Center on February 14, 1994, and report results to Program Manager on February 28, 1994
- Develop a program plan for the National Wind Tunnel Complex (NUTC) which utilizes best business practices
- Generate a cost estimate for Concept D - Option 5 which utilizes a best business practices approach for Project accomplishment. An assessment of cost uncertainties should be included
- Produce a master schedule which reflects timelines for best business practices and "fast track" scheduling
- Examine other design and construction approaches which may render savings in cost and schedule
- Identify urgent design studies

# Joint Industry Government Team

## **AEDC/Calspan**

Travis Binion  
Frank Jackson  
Lowell Keel  
Jim Parker  
Philip Stich

## **Aero Systems Engineering, Inc. (ASE) (FluidDyne)**

Dean Long  
Tom Moll  
Leon Ring  
Leon Zacho

## **Boeing**

Bill Dodge  
Bob Doerzbacher  
Art Fanning  
Kevin Watson

## **General Electric**

Don Dusa

## **McDonnell Douglas**

Dave Lalor  
Dale Siegele

## **NASA Headquarters**

Ralph Spillinger  
Bill Stamper

## **NASA ARC**

Nancy Bingham  
Dan Bufton  
Dave Englebert  
Ken Mort  
Frank Steinle

## **NASA LaRC**

Earl Booth  
Norma Davis  
Dennis Fuller  
Blair Gloss  
Drew Hagemann  
Carl Horne  
Ken Jacobs  
Sammie Joplin  
Seun Kahng  
Charles Laney  
Henry Livas  
Tom Quenville  
Trish Romanowski  
John Taylor

## **NASA LaRC (cont.)**

Bobby Wallis  
George Ware  
Henry Wright

## **NASA LeRC**

Joe Ziemianski

## **Sverdrup Technology, Inc.**

Jim Gunn  
Ron Hamilton  
Ward Johnson  
Ed Rimpley  
Willard Summers  
Jim Thorington  
Jim Young

## **Process Employed by Team**

- Technical groups (WBS 1000-7000) initially reviewed scope and cost of elements in FSO concept A and Boeing concept (1991). Goal was a mutual understanding of technical approaches and costing techniques. Cost adjustments were made when obvious errors were found. Cost differences associated with different technical approaches and risk perception remain unresolved
- Technical groups transitioned to Concept D - Option 5 and reviewed FSO's estimate and adjusted cost at the lowest WBS level where data was available. Consensus was attempted in all cases for the costing exercise
- Project schedule group initially developed high level logic elements and relationships. A sub-group generated the detailed logic elements with associated relationships and assigned tentative durations. Entire group reviewed resulting network and adjusted until consensus was reached

## **Process Employed by Team**

- **Management groups reviewed Boeing-proposed Consortium model, developed an alternative Consortium model, and examined issues associated with formation of a Consortium, acquisition approach for the NWTC, and operation of the NWTC**
- **Best business practices were identified by the management group and combined with the Consortium model to render an overall Project management model**
- **Costs for Concept D - Option 5 in areas of project management and cost adders were modified to reflect the new Project management model**
- **Cost changes from technical and management groups were combined to provide a composite cost estimate for a Consortium based implementation of the NWTC**

## **Best Business Practices**

- **NWTC is managed as a single business unit**
  - **One person in charge**
  - **Consortium members provide dedicated staff including administrative and Systems Engineering staff**
- **Provide cash flow consistent with projected spending plan**
- **Use of design/build and Concurrent Engineering**
- **Use a streamlined procurement process**
  - **Use of pre-qualified bidders**
  - **Industry approach to source selection**
- **Mature the design and validate requirements through preliminary design before finalizing the cost and schedule**
- **Use contract incentives as appropriate**
- **Component/subsystem validation and inspection is conducted by the supplier**

## Executive Summary

- Consensus reached on Joint Industry Government Report
- Cost history
 

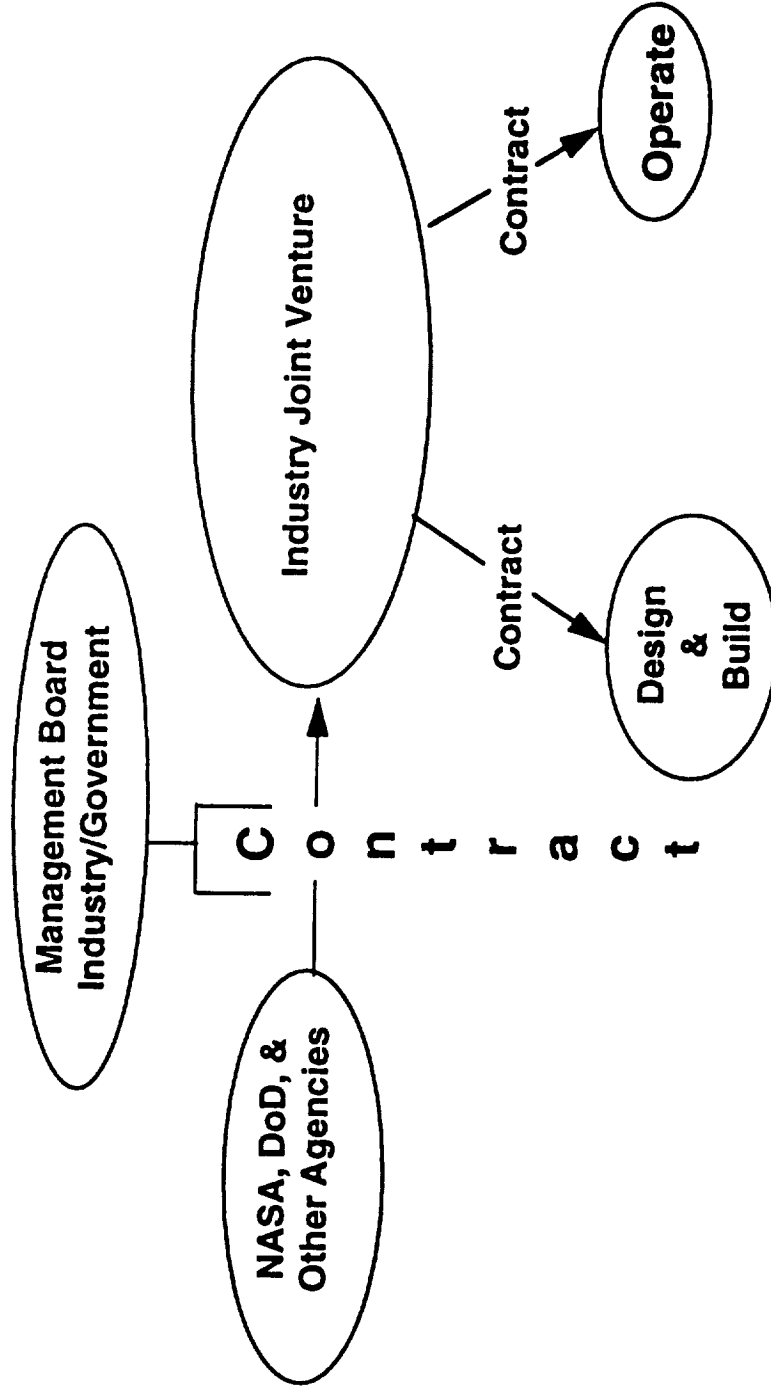
– FSO August 1993		\$3.22B
– Joint Industry Government Team reductions		
• Technical approach	- 0.34	2.88
• Government Project Office staff/travel	- 0.11	2.77
• Consortium Project Management model (Best Business Practices)	- 0.22	\$2.55B
- Schedule history  
(Conceptual design to calibration complete)
 

– FSO August 1993	9.5 years
– JIGT Project Mgt. Model	8 years
- Implement risk reduction phase

# **Consortium Models**

# Boeing Consortium Model

## Consortium



## **Boeing Consortium Model**

- Government pays total capital cost on a cost reimbursable basis including Joint Venture staffing costs
- Management Board is made up of representatives of Industry and Government and provides oversight of the other two participating groups
- NASA, DoD, and other agencies administer the contract between the Government and Industry Joint Venture
- Industry Joint Venture contracts for and manages the design, siting, acquisition, and operation of the NWTCT
  - A Not For Profit entity on a cost reimbursable basis
  - Tasks contracted to member organizations
  - Contracts using “Best Commercial Practices” by member purchasing agents
  - Government owns facility
- Consortium allocates wind tunnel use rights
- Consortium establishes membership and membership transfer requirements
- Government guarantees site-related cost equals “Best Commercial Practices”

## **Definition Required**

- Participant relationships/responsibilities
  - Management Board Industry Government
  - NASA, DOD, and other agencies
  - Industry Joint Venture
  - Executive Branch/Congress
- Consortium agreement
  - Authority (change approval, reimbursables, etc.)
  - Liability
  - Cost sharing (capital, overruns, etc.)
  - Incentives to performing organization
  - Concept of operation
- Consortium organization/business plan
  - Leadership
  - Membership
  - Staffing
  - Location

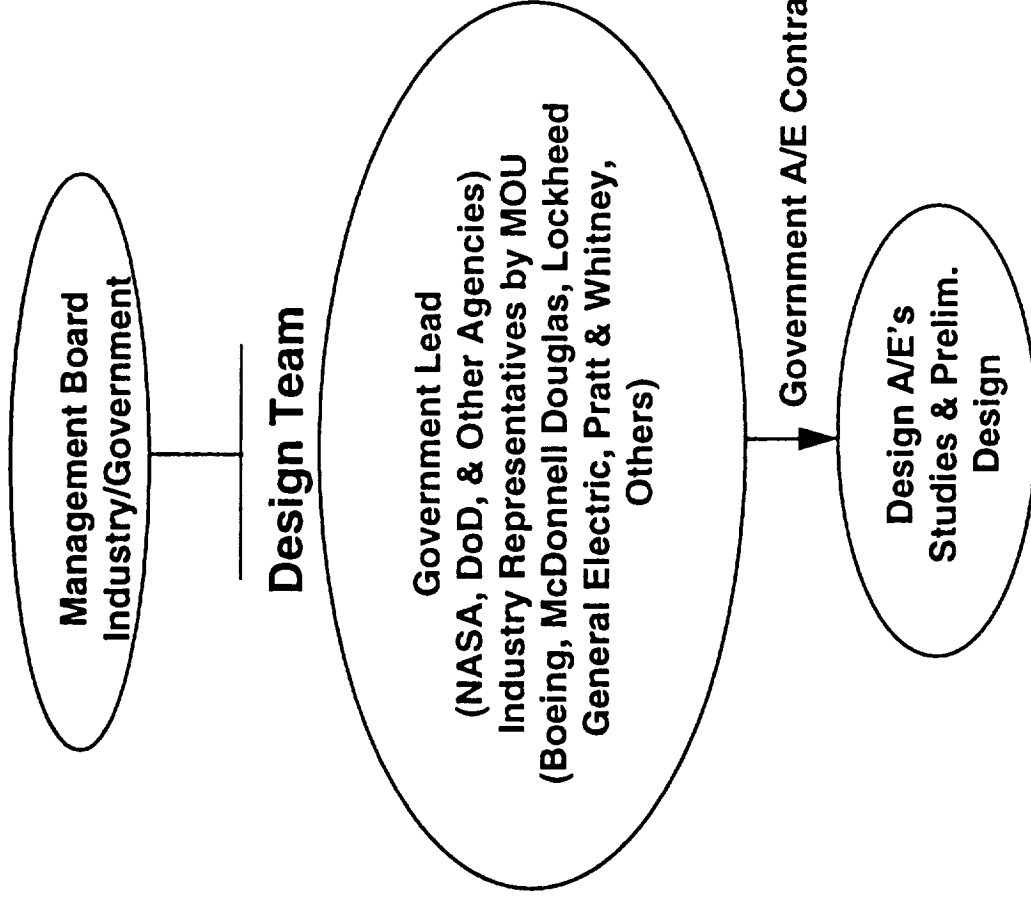
# **Phased Consortium Model**

## **Joint Industry Government Team Phased Consortium Model**

- **The Joint Industry Government Team Phased Consortium Model addresses three key issues raised with regard to the Boeing Proposed Consortium Format**
  - **How do you obtain Government input and expertise in the Design process?**
  - **How do you mitigate the risk to both the Government and the Industry Joint Venture?**
  - **How do you minimize the schedule impact of the formation of the Industry Joint Venture and Government Contract?**

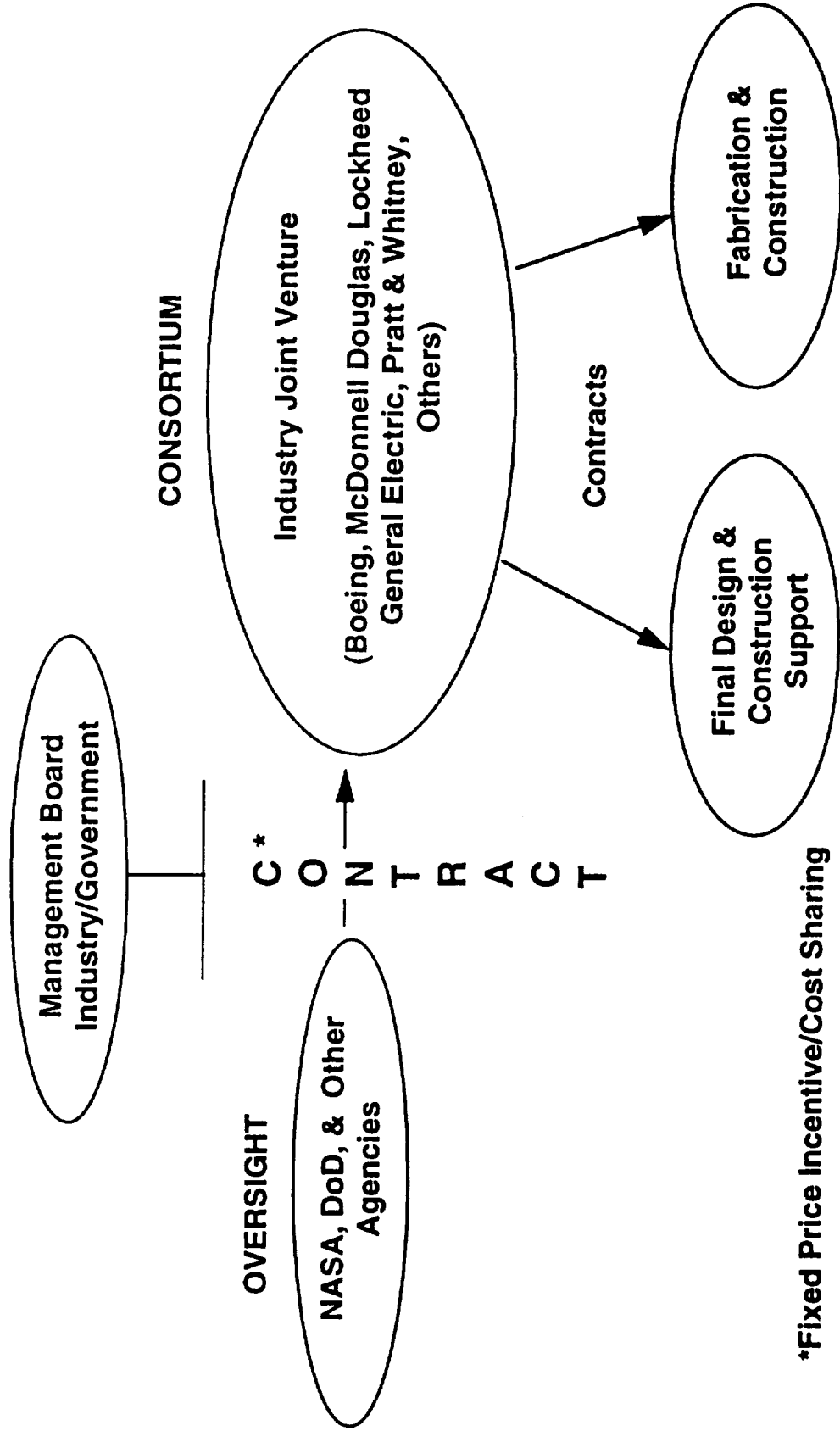
# Phased Consortium Model

## Phase I Risk Reduction



# Phased Consortium Model

## Phase II Final Design & Construction



\*Fixed Price Incentive/Cost Sharing



## **Joint Industry Government Team Phased Consortium Model**

- The Phased Consortium Model provides for:
  - Government and Industry participation in the development of value engineering and risk reduction approaches during the study and preliminary design phase
  - The Government leads the effort to the 30% design level, maturing design concepts and validating requirements, cost, and schedule thereby significantly reducing risk
  - The Phase I Model allows for the timely start of studies and preliminary design and provides up to 18 months for the creation of the Industry Joint Venture and contracts with the Government without impact to the project initiation

## **Joint Industry Government Team Phased Consortium Model**

- **Phase I Risk Reduction**
  - The Phase I Design Team is led by the Government with representatives (via MOU's) from Industry and has responsibility for studies and preliminary design to the 30% level
- The Government contracts with A/E firms to perform studies and preliminary design
- The work is performed at distributed locations with electronic and video linkage or at a single location with management and systems engineering representatives co-located

# Urgent Critical Path Studies for Design

## First 3 to 6 months

	<u>K\$</u>
• External balance load path and shell envelope and anchor point	100
• Isolation valves	225
• TSWT choke and re-entry	250
• Preliminary cart/test section/model support integration	500
• TSWT/LSWT integrated studies	600
– Aero lines	
– Internals	
– Acoustics	
• LSWT open jet aero performance	60
• Test-section wall interference	45
	<hr/>
	1,780

## **Joint Industry Government Team Phased Consortium Model**

- **Phase II Final Design and Construction and Phase III Activation and Operation**
  - **The Phase II and Phase III consortium models modify the Boeing Proposed Consortium Model**
  - **Contracting to the Joint Venture is performed by a Fixed Price Incentive contract**
  - **Government shares cost with Industry (undetermined share split)**
  - **Novation of the design contract to the Industry Joint Venture for design completion, or Industry Joint Venture negotiate a final design contract**

## Schedule and Initiation Requirements

QRT 1	QRT 2	QRT 3	QRT 4	QRT 5	QRT 6	QRT 7
START-UP						
T.O.	URGENT STUDIES					
	A/E ACQUISITION	RISK REDUCTION TO 30% DESIGN				

- **Required actions**

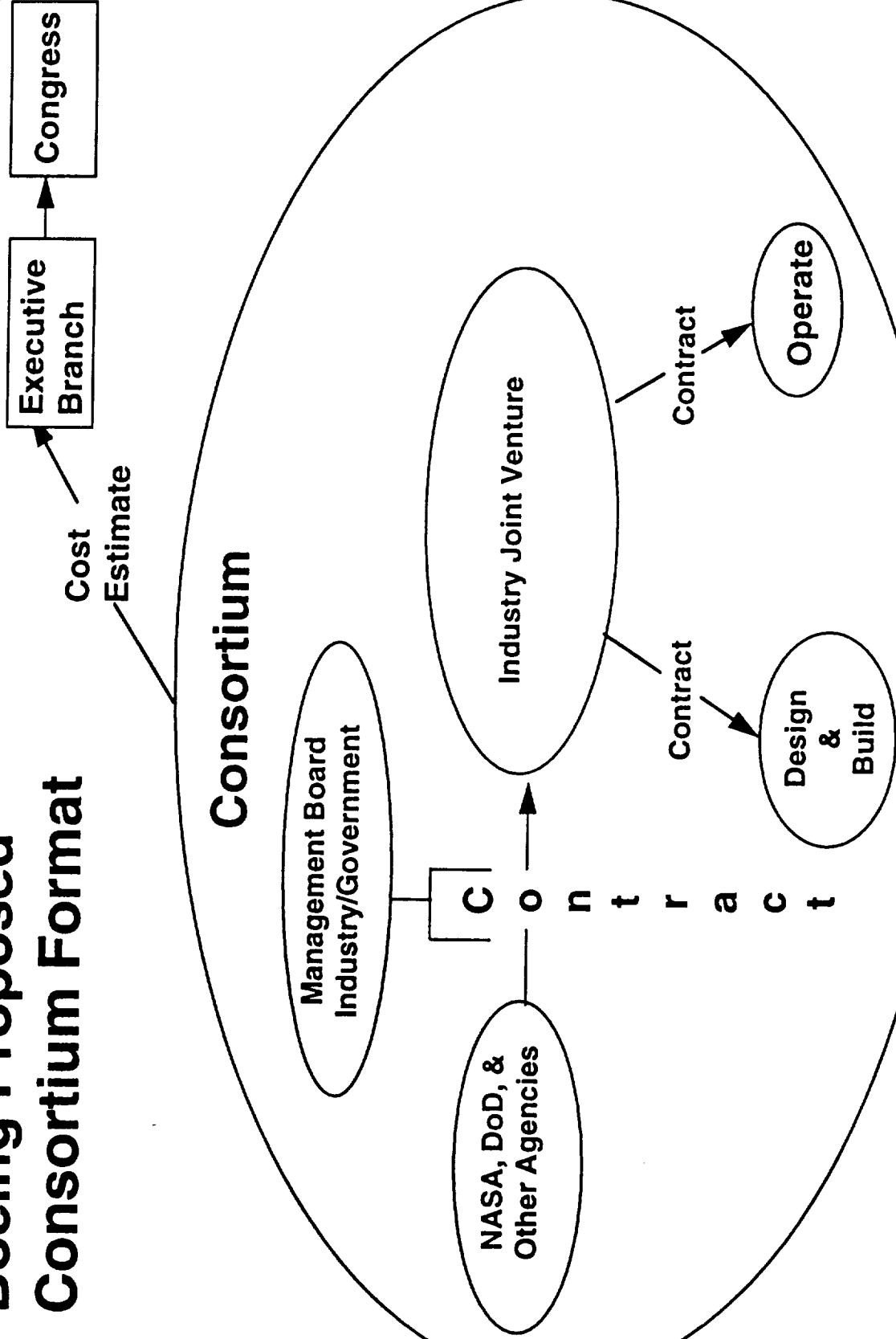
- **Release of study funds**
- **Initiate design acquisition prior to receipt of design funds**
- **Waivers to OMB Circular A-109 for plans, reviews, and approvals**
- **Waivers to NMI 1720.4 Management of Major Systems Programs and Projects for plans, reviews, and approvals**

## **Consortium Contract Model**

- **Fixed Price/Incentive Contract**
  - **Target Cost - Established at System Design Review (30% design completion level)**
  - **Ceiling Cost - Established at Program Approval based on budgetary estimate**
- **Incentives for Target Cost exceedence will be amortized over the life of the facility**
  - **Fees for facility usage by Consortium members will be increased based on a share curve with payback to the Government**
- **Ceiling cost exceedence may result in program cancellation**

**Cost**

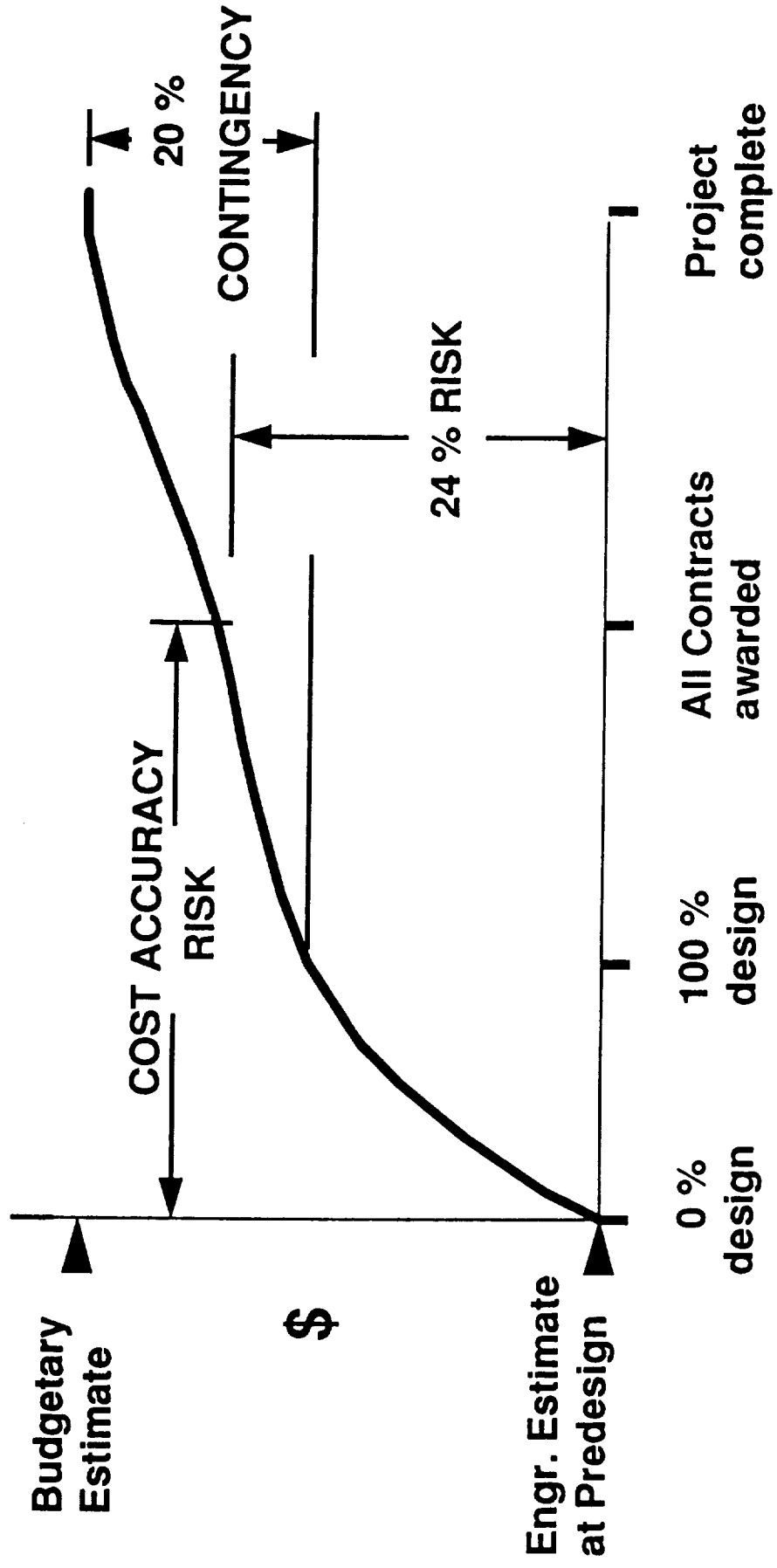
# Boeing Proposed Consortium Format



## **Cost Estimating Instructions**

- 1. All WBS elements cost estimates include:**
  - In place cost**
  - Sales tax (6% of materials, equipment, rentals)**
  - Profit**
- 2. Risk accounts for cost estimating accuracy at lowest level of WBS estimate**
- 3. Design contractors responsible for correcting errors and omissions**
- 4. Field indirects are in WBS 8000**
- 5. Engineering level estimate is July 1993 dollars**
- 6. Subcontractor bond premium 0.8% of construction cost**
- 7. Escalation is 3.5%/year to mid-point of construction**
- 8. Contingency is 20%**

# COST ESTIMATE MODEL



NATIONAL WIND TUNNEL COMPLEX				
CONCEPT D Option 5				
COST ESTIMATE				
(Dollars in Thousands)				
WBS	DESCRIPTION	Government Procurement	Consortium Procurement	
		9/3/93	JIGT(8/25/94)	
		Estimate	Estimate	
1000	Site And Infrastructure	\$59,678	\$58,270	
2000	Buildings	\$103,058	\$103,074	
3000	Auxiliary Process System	\$148,947	\$114,408	
4000	Low Speed Wind Tunnel	\$408,948	\$386,622	
5000	Transonic Speed Wind Tunnel	\$352,514	\$320,997	
7000	Operations (LSWT & TSWT)	\$106,479	\$89,056	
8000	Management And Support	\$198,671	\$135,370	
	Engineering Estimate	\$1,378,295	\$1,207,797	
	Risk	\$333,689	\$294,394	
	Subtotal	\$1,711,984	\$1,502,191	
	Profit	\$171,198	\$0	
	Bond	\$18,832	\$12,018	
	Escalation	\$513,544	\$347,140	
	Contingency	\$241,556	\$372,270	
	Construction Management(6%)	\$159,427	\$134,017	
	Engineering Support(2%)	\$53,142	\$44,672	
	Total Construction Budget	\$2,869,683	\$2,412,308	
	PER	\$46,000	\$0	
	Government PM	\$151,005	\$28,645	
	Studies	\$38,523	\$8,660	
	Design	\$118,181	\$100,800	
	PROJECT TOTAL	\$3,223,393	\$2,550,412	

## Changes in Cost Estimate WBS Elements

WBS	FSO 9/3/93	JIGT 2/28/94	Delta Cost	Changes
1000	\$59,678K	\$58,270K	(\$1,408K)	<ul style="list-style-type: none"> <li>Reduction in yard electrical cost due to reduction of one low pressure air compressor and one high pressure air compressor</li> </ul>
2000	\$103,058K	\$103,074K	+ \$16K	<ul style="list-style-type: none"> <li>Several minor changes</li> </ul>
3000	\$148,947K	\$114,408K	(\$34,539K)	<ul style="list-style-type: none"> <li>Eliminate one low pressure air compressor</li> <li>Eliminate one high pressure air compressor</li> <li>Reduce capacity from 70 pps to 50 pps</li> <li>Eliminate one high pressure air dryer</li> <li>Reduce air storage from 7,000 cu. ft. to 6,000 cu. ft.</li> <li>Reduce air distribution line size from 10" to 8"</li> <li>Reduce cooling capacity to design point vs full load</li> <li>Estimated staff size for auxiliary test vs using % of installed cost</li> </ul>

# Changes in Cost Estimate WBS Elements

(continued)

WBS	FSO 9/3/93	JIGT 2/28/94	Delta Cost	Changes
4000	\$408,948K	\$386,622K	(\$22,326K)	<ul style="list-style-type: none"> <li>• Eliminated three 300-ton cranes</li> <li>• Reduced capacity of remaining crane to 100 tons</li> <li>• Reduced size of turning vanes</li> <li>• Reduced risk on screens and honeycomb</li> <li>• Reduced test, validation, and calibration cost</li> </ul>
5000	\$352,514K	\$320,997K	(\$31,517K)	<ul style="list-style-type: none"> <li>• Eliminated three 300-ton cranes</li> <li>• Reduced capacity of remaining crane to 100 tons</li> <li>• Increased cost of flexible nozzle due to oversight</li> <li>• Reduced test section cart cost due to double bookkeeping</li> <li>• Reduced test, validation, and calibration cost</li> </ul>

## Changes in Cost Estimate WBS Elements

(continued)

WBS	FSO 9/3/93	JIGT 2/28/94	Delta Cost	Changes
7000	\$106,479K	\$89,056K	(\$17,423K)	<ul style="list-style-type: none"> <li>• Delete external balance calibration cost (included in WBS 4000 and 5000)</li> <li>• Minor reduction in instrumentation and data acquisition cost</li> </ul>
8000	\$198,671K	\$135,370K	(\$63,301K)	<ul style="list-style-type: none"> <li>• Reduction in size of staff for integration contractor</li> <li>• Reduction in maintenance and operation support during construction</li> <li>• Reduction in field indirects</li> </ul>

## Changes in Cost Estimate WBS Elements Summary

WBS	FSO 9/3/93	JIGT 2/28/94	Delta Cost
1000	\$59,678K	\$58,270K	(\$1,408K)
2000	103,058K	103,074K	+16K
3000	148,947K	114,408K	(34,539K)
4000	408,948K	386,622K	(22,326K)
5000	352,514K	320,997K	(31,517K)
7000	106,479K	89,056K	(17,423K)
8000	<u>198,671K</u>	<u>135,370K</u>	<u>(63,301K)</u>
	\$1,378,295K	\$1,207,797K	(\$170,498K)

# Changes in Cost Estimate Risk

(Cost Estimating Accuracies)

Source	Percent	Cost	Remarks
FSO 9/3/93	24% (Engineering Estimate)	\$333,689K	<ul style="list-style-type: none"> <li>• Deviations in cost estimate at lowest level of WBS</li> </ul>
JIGT 2/28/94	24% (Engineering Estimate)	\$294,394K	<ul style="list-style-type: none"> <li>• No change in risk assessment</li> </ul>

## Changes in Cost Estimate Profit

Source	Percent	Cost	Remarks
FSO 9/3/93	10% (Construction Cost)	\$171,198K	<ul style="list-style-type: none"> <li>• WBS cost is in-place cost for subcontracts</li> <li>• Two additional levels of profit                             <ul style="list-style-type: none"> <li>– Prime contractor at 5%</li> <li>– General contractors at 5%</li> </ul> </li> </ul>
JIGT 2/28/94	0%	- 0 -	<ul style="list-style-type: none"> <li>• WBS cost is in-place cost for subcontracts and integration contract</li> <li>• Joint Venture Group is a not-for-profit organization</li> <li>• Best Business Practice                             <ul style="list-style-type: none"> <li>– Zero profit for pass-through work</li> </ul> </li> </ul>

## Changes in Cost Estimate Bond

Source	Percent	Cost	Remarks
FSO 9/3/93	1% (Construction Cost + Profit)	\$18,832K	<ul style="list-style-type: none"> <li>Applied to WBS elements</li> </ul>
JIGT 2/28/94	0.8% (Construction Cost)	\$12,018K	<ul style="list-style-type: none"> <li>Recommendation from one source that this could be eliminated by selection of contractors with assets greater than contract value</li> <li>Re-evaluation of fee rate indicates that 0.8% is achievable</li> </ul>

## Changes in Cost Estimate Escalation

Source	Percent	Cost	Remarks
FSO 9/3/93	3.5% (Construction Cost + Profit + Bond)	\$513,544K	<ul style="list-style-type: none"> <li>• Midpoint of construction - 7 years</li> <li>• Schedule to complete - 9.5 years</li> <li>• Basis for WBS cost numbers - July 1993</li> </ul>
JIGT 2/28/94	3.5% (Construction Cost + Bond)	\$347,140K	<ul style="list-style-type: none"> <li>• Midpoint of construction is July 1999 - 6 years from July 1993 cost basis and 5 years from April 1994 project start date</li> <li>• Cost reduction from                             <ul style="list-style-type: none"> <li>– Lower engineering level estimate</li> <li>– Zero profit</li> <li>– One year less to midpoint of construction</li> </ul> </li> </ul>

## Changes in Cost Estimate Contingency

Source	Percent	Cost	Remarks
FSO 9/3/93	10% (Construction Cost + Profit + Bond + Escalation)	\$241,556K	<ul style="list-style-type: none"> <li>• Relative low contingency associated with project plan                             <ul style="list-style-type: none"> <li>– Design complete before start of construction</li> <li>– Fixed Price contracts</li> <li>– Government Project Office responsible for Systems Engineering and integration</li> </ul> </li> </ul>
JIGT 2/28/94	20% (Construction Cost + Bond + Escalation)	\$372,270K	<ul style="list-style-type: none"> <li>• Industry Joint Venture Group is not for profit and has no assets</li> <li>• Industry Joint Venture and Government share cost risk</li> <li>• Schedule risk has increased</li> </ul>

## Changes in Cost Estimate Construction Management/Engineering Support (SIES)

Source	Cost	Remarks
FSO 9/3/93	<div> <div>Constr. Mgt.    \$159,427K</div> <div>Engr. Support    <u>53,142K</u></div> <div>\$212,569K</div> </div>	<ul style="list-style-type: none"> <li>• Construction management estimated as 6% of total construction cost plus contingency</li> <li>• Engineering support during construction estimated as 2% of total construction cost plus contingency</li> </ul>
JIGT 2/28/94	<div> <div>Constr. Mgt.    \$134,017K</div> <div>Engr. Support    <u>44,672K</u></div> <div>\$178,689K</div> </div>	<ul style="list-style-type: none"> <li>• Reduction in cost due to lower construction cost</li> </ul>

## **Construction Management Scope**

- |   |                                |
|---|--------------------------------|
| <b>1. Site logistics planning</b>               | <b>8. Safety</b>               |
| <b>2. Procurement</b>                           | <b>9. Environmental</b>        |
| <b>3. Contract administration</b>               | <b>10. Obtain permits</b>      |
| <b>4. Change control</b>                        | <b>11. Site supervision</b>    |
| <b>5. Cost control</b>                          | <b>12. Surveying services</b>  |
| <b>6. Schedule development/<br/>maintenance</b> | <b>13. Inspection services</b> |
| <b>7. R&amp;QA/QC</b>                           | <b>14. Testing services</b>    |

## **Engineering Support During Construction**

### **Scope:**

- 1. Additional design to upgrade performance**
- 2. Technical assistance during construction**
- 3. Shop drawing review**
- 4. Bid package preparation and recommendation**
- 5. Vendor coordinate**
- 6. O&M manuals - individual WBS**
- 7. Test plans**
- 8. Record drawings (As Built configuration)**
- 10. Training**
- 11. Configuration control**
- 12. Technical consultants**

## Changes in Cost Estimate PER

Source	Percent	Cost	Remarks
FSO 9/3/93	2%	\$46,000K	<ul style="list-style-type: none"> <li>Preliminary Engineering Report to identify concepts and estimate cost</li> </ul>
JIGT 2/28/94	- 0 -	- 0 -	<ul style="list-style-type: none"> <li>Current definition of project considered adequate to start risk reduction phase and carry project to 30% design level</li> </ul>

## Changes in Cost Estimate Government Project Management

Source	Cost	Remarks
FSO 9/3/93	\$151,005K	<ul style="list-style-type: none"> <li>• Responsibility identified as: Project Management, Systems Engineering, and Integration</li> <li>• Staffing level <ul style="list-style-type: none"> <li>– Civil servants 25</li> <li>– Support service contract staff 91</li> </ul> </li> </ul> <div style="text-align: right; margin-top: 10px;"> <u>116</u> </div> <ul style="list-style-type: none"> <li>• Other cost included <ul style="list-style-type: none"> <li>– Travel</li> <li>– Technical reviews</li> <li>– Technical consultants</li> <li>– Environmental support</li> </ul> </li> </ul>
JIGT 2/28/94	\$28,645K	<ul style="list-style-type: none"> <li>• Responsibility of GPO relative to Industry Joint Venture Group is not defined</li> <li>• Management decision to staff with civil servants and eliminate travel</li> </ul>

## Changes in Cost Estimate Studies

Source	Cost	Remarks
FSO 9/3/93	\$38,523K	<ul style="list-style-type: none"> <li>• Studies identified through two workshops</li> </ul>
JIGT 2/28/94	\$8,660K	<ul style="list-style-type: none"> <li>• Reduction in number of studies and moving studies into design and project planning</li> </ul>

## Changes in Cost Estimate Design

Source	Cost	Remarks
FSO 9/3/93	\$118,181K	<ul style="list-style-type: none"> <li>• Cost of design estimated at lowest level of WBS</li> </ul>
JIGT 2/28/94	\$100,800	<ul style="list-style-type: none"> <li>• Identified approaches in several areas that simplified design as well as reducing construction cost</li> <li>• Included cost for 19 studies</li> </ul>

# Schedule

# Schedule Acceleration Technique

<u>Organizational</u>	<u>Design</u>	<u>Construction</u>	<u>Checkout</u>
<ul style="list-style-type: none"> <li>- Establish operating informal Joint Venture</li> <li>- Reporting to NASA Administrator/Corporate President level</li> <li>- Dedicated Acquisition staff</li> <li>- Dedicated Legal staff</li> <li>- Adopt Best Business Practices</li> <li>- Detail Project Planning Phase</li> <li>- Release of design funds to Program Office</li> <li>- Early site selection</li> <li>- Co-location of Joint Venture at site</li> <li>- Multiple Environmental Impact Statements</li> <li>- Establish multiple A/E contracts</li> </ul>	<ul style="list-style-type: none"> <li>- Overtime</li> <li>- Schedule-driven awards</li> <li>- Early order of long lead items</li> <li>- Construction of foundation on critical path</li> <li>- Selective bidders' list for design/build items. Multiple awards for design phase</li> <li>- Parallel design of wind tunnel shell and internals</li> <li>- Verification of systems level requirements</li> <li>- Concurrent engineering</li> <li>- Initiate design in April 1994</li> </ul>	<ul style="list-style-type: none"> <li>- Schedule-driven awards</li> <li>- Incentive contracts for cost and schedule reduction</li> <li>- Maintenance and operations contract for all completed systems</li> </ul>	<ul style="list-style-type: none"> <li>- Multiple shifts</li> <li>- Overtime</li> <li>- Systems Engineering and contractor support for redesign, modification, and repair.</li> </ul>



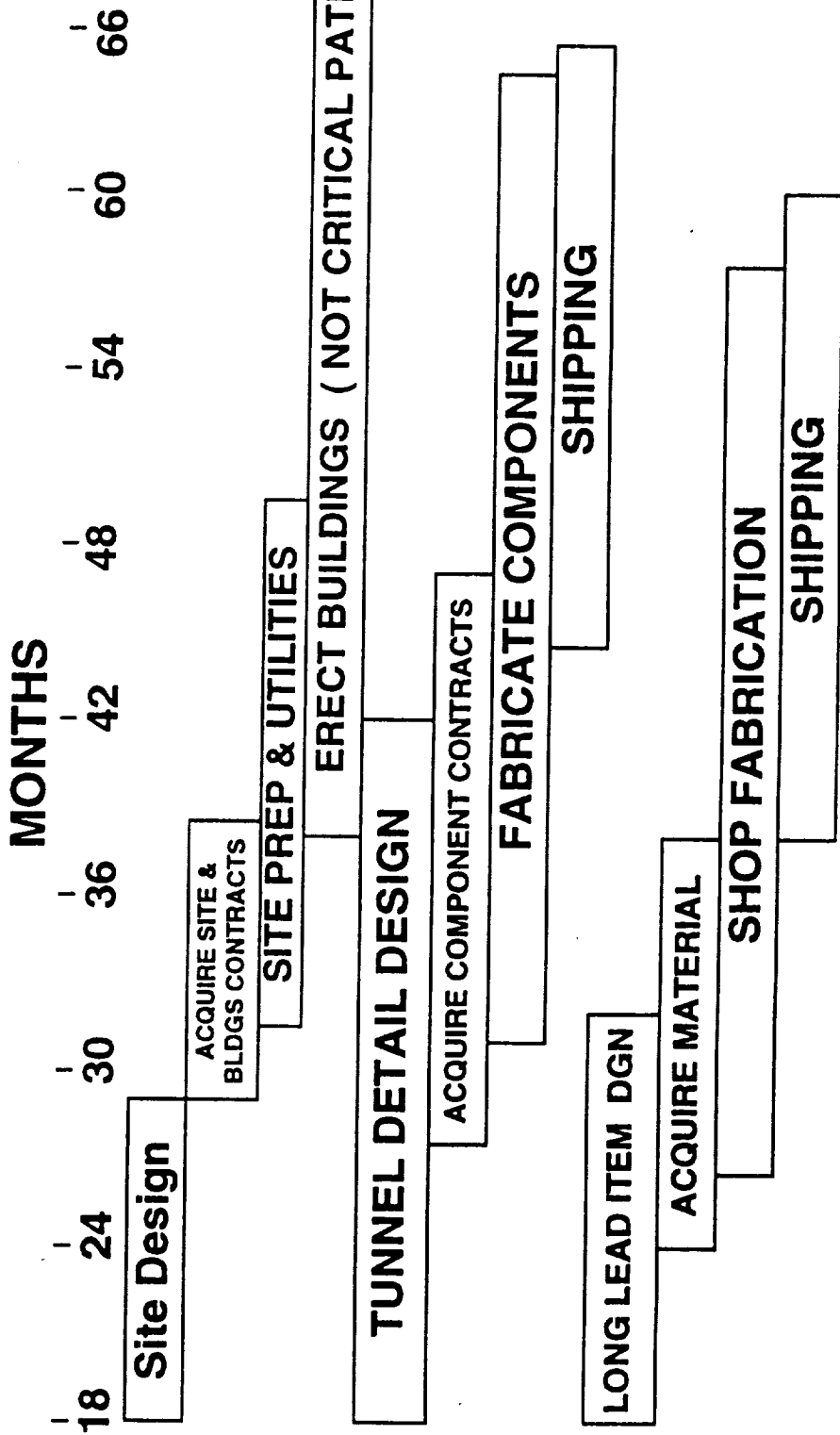
## **KEY SCHEDULING ASSUMPTIONS (1)**

- Consortium formation not part of schedule.
- April 1, 1994 project notice to proceed.
- Funding is available when required by the accelerated schedule.
- Expedited procurement cycles for urgent studies (1 month), tunnel design (3 months) and site design contracts(4 months).
- Site selected in 8 months from project start .
- Total site selection/ EIS /permits process is 18 months.

## **KEY SCHEDULING ASSUMPTIONS (2)**

- **Use preliminary specifications to award wind tunnel shells and drive systems design/ build contracts.**
- **Build to print contracts for wind tunnel internal components and auxiliary equipment.**
- **Concurrent engineering / construction used for all major project activities.**
- **Conduct of sub-system, system and integrated systems checkouts.**
- **Multiple shifts and overtime for integrated systems checkouts and calibrations.**
- **Calibration durations reduced to 3 months for LSWT and 4 months for TSWT.**

# NWTC SCHEDULE PROCUREMENT



## **KEY SCHEDULING RESULTS**

- Urgent studies must begin May 1994.
- Preliminary design begins October 1994.
- Site selection required December 1994.
- Site specific design begins January 1995.
- Shell erection begins June 1997.
- All designs complete November 1997.
- LSWT drive system delivered September 1998.
- Midpoint of construction is July 1999.
- Project complete March 2002. Eight year duration.
- TSWT is ready for testing on December 2001.
- Hydrostatic tests for shells establishes constraints for many activities.

## Typical Wind Tunnel Project Durations

Facility	Start Date	End Date	Duration (yrs)
AEDC			
ASTF	11/1/72	9/1/85	12.8
J6	1/1/84	11/1/94	10.8
ARC			
40X80 Tunnel	1/1/74	6/1/87	13.4
12 Foot PWT	6/1/87	9/1/95	8.3
LaRC			
NTF	2/1/74	9/1/84	10.6
8 Foot HTT	1/1/83	7/1/93	10.5
Europe			
ETW	6/1/85	10/1/94	9.3

### Notes:

Start date is receipt of conceptual design funds

End date is completion of tunnel calibration

## **Schedule Risk**

- **Zero slack in 8-year schedule**
- **Schedules of recent wind tunnel projects range from 8 years to 13 years**
- **Size of NWTTC is larger/higher cost requiring more coordination**
- **Implementation of project with Best Business Practices and risk reduction phase is essential to meet schedule and control cost**

# Critical Items and Actions

## **Critical Items and Actions**

- **Capital cost considered high**
  - **Constrained Federal budget environment**
  - **Industry investment requirements**
- **Schedule to complete exceeds need date**
  - **Industry needs tunnels operational in year 2000**
    - **Schedule indicates operational 2002 with April 1994 start date**
    - **Historical data indicates 8 years or more to complete wind tunnel projects**
- **Project contains areas of technical risk**
  - **Loads, stiffness, and envelope requirements exceed state of the art for the external balance**
  - **Others may develop during Systems Engineering phase**

## **Critical Items and Actions**

(continued)

### **Recommendation: Implement risk reduction phase**

- **Cost risk**
  - Conduct System Requirements Review
  - Complete design to 30% level/estimate cost
    - Value Engineering to select cost-effective approaches
    - Improve cost estimating accuracy
  - Validate design and cost estimate
- **Schedule risk**
  - Develop systems level schedule
  - Identify subsystems interfaces
  - Validate time to accomplish events
  - Develop alternative schedule logic to minimize time to complete
- **Technical risk**
  - Define system characteristics and configurations to meet National Consensus requirements
  - Identify high technical risk/high cost/long lead items
  - Develop alternatives

**National Wind Tunnel Complex**  
**Joint Industry Government Team**

**Appendix 8**

**Report of the Joint Industry  
Government Team to the  
Administrator**

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# **Report of Joint Industry Government Team**

**March 4, 1994**

## **Joint Industry Government Team**

- **Supporting Organizations**

**AEDC**

**Boeing**

**Calspan**

**Aero Systems Engineering, Inc.  
(FluidDyne)**

**General Electric**

**McDonnell Douglas**

**NASA Ames**

**NASA Headquarters**

**NASA Langley**

**NASA Lewis**

**Sverdrup**

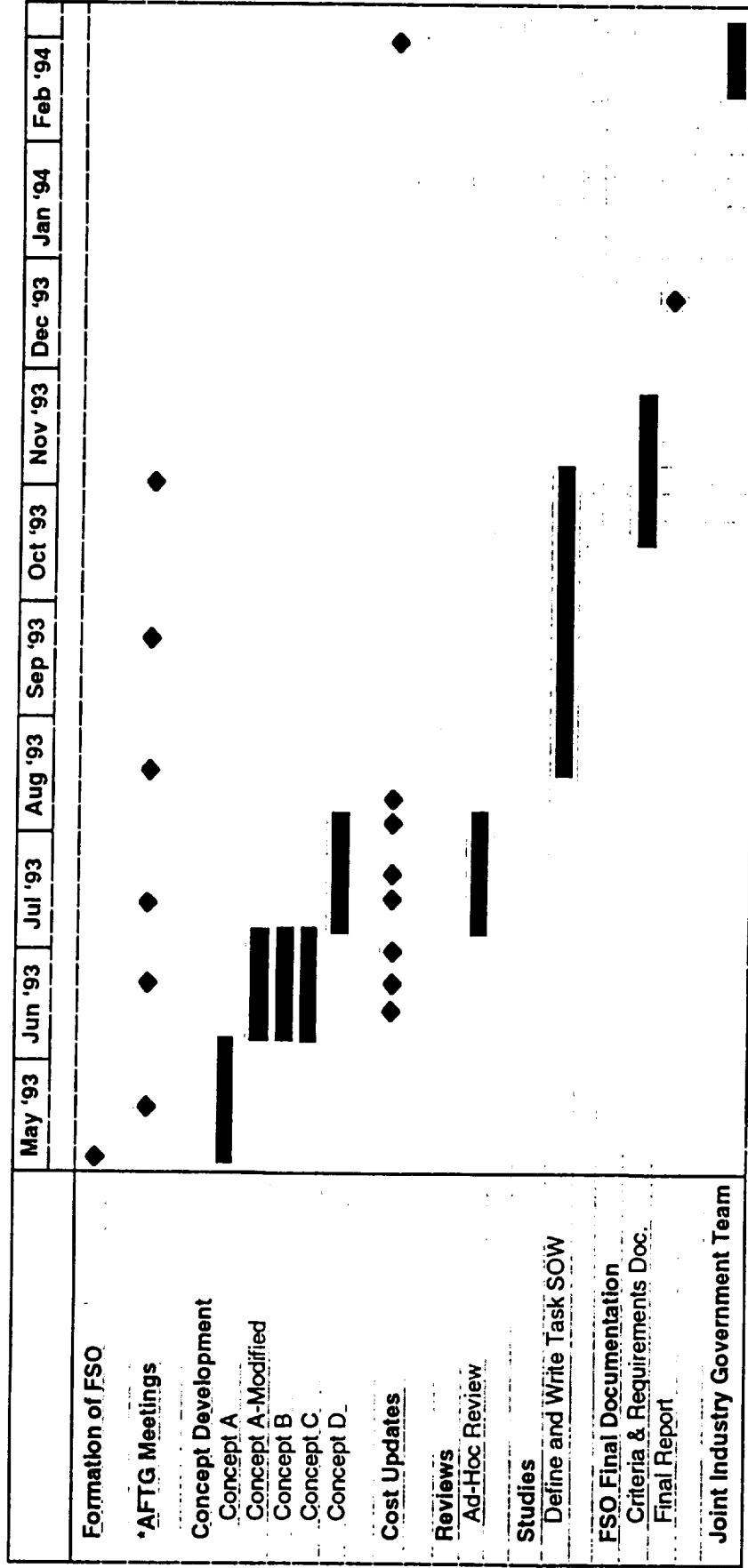
- **Consensus reached by the team on technical approach, schedule, and cost**

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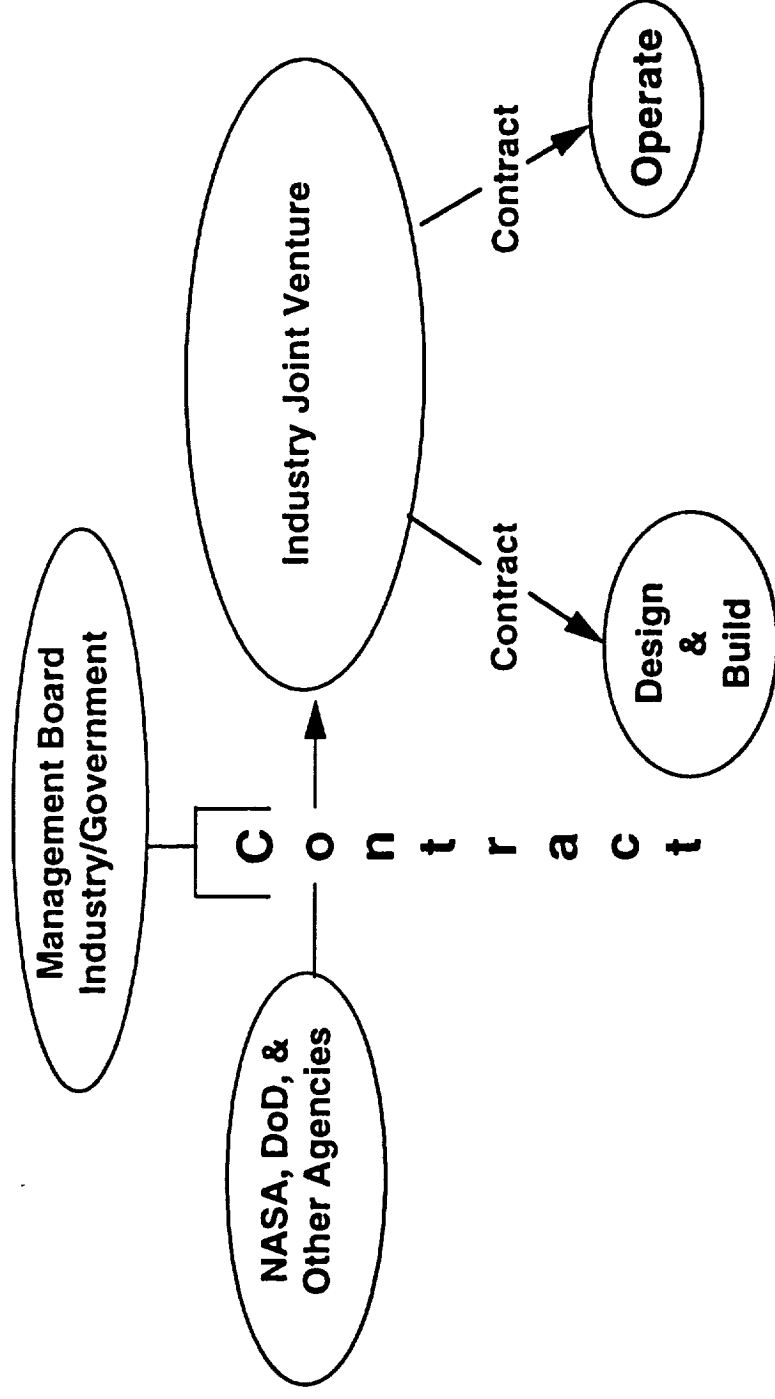
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# National Wind Tunnel Complex Definition



\* Aeronautical R&D Facilities Task Group (National Facility Study)

# Consortium Model



## **Best Business Practices**

- **Manage Industry Joint Venture as a single business unit**
  - One person in charge
  - Dedicated staff including administrative and systems engineering
- **Provide cash flow consistent with spending plan**
- **Use design/build and concurrent engineering**
- **Use a streamlined procurement process**
  - Pre-qualified bidders
  - Industry approach to source selection
- **Mature the design and validate requirements through preliminary design before finalizing the cost and schedule**
- **Use contract incentives**
- **Validation and inspection by the supplier**

# Schedule Acceleration Techniques

<u>Organizational</u>	<u>Design</u>	<u>Construction</u>	<u>Checkout</u>
<ul style="list-style-type: none"> <li>- Establish informal Joint Venture</li> <li>- Reporting to a high management level</li> <li>- Dedicated Acquisition staff</li> <li>- Dedicated Legal staff</li> <li>- Adopt Best Business Practices</li> <li>- Detail Project Planning Phase</li> <li>- Release of design funds</li> <li>- Locate Joint Venture at site</li> <li>- Multiple Environmental Impact Statements</li> <li>- Establish design contracts</li> </ul>	<ul style="list-style-type: none"> <li>- Overtime</li> <li>- Schedule-driven awards</li> <li>- Early order of long lead items</li> <li>- Start critical construction during design phase</li> <li>- Selective bidders' list for design/build items.</li> <li>- Parallel design of wind tunnel shell and internals</li> <li>- Verification of systems level requirements</li> <li>- Concurrent engineering</li> </ul>	<ul style="list-style-type: none"> <li>- Schedule-driven awards</li> <li>- Incentive contracts for cost and schedule reduction</li> <li>- Maintenance and operations contract for all completed systems</li> </ul>	<ul style="list-style-type: none"> <li>- Multiple shifts</li> <li>- Overtime</li> <li>- Systems Engineering and contractor support for redesign, modification, and repair.</li> </ul>

## **Key Scheduling Assumptions**

- **Joint Venture formation complete 3 months after start**
- **Sole source procurement to Joint Venture approved 3 months after start**
- **Funding available when required**
- **Site selected 8 months after project start**
- **Total site selection/EIS/permits process complete 18 months after project start**

## **Major Milestones**

- **Site selection complete December 1994**
- **Preliminary design begins December 1994**
- **First hardware contract award December 1995**
- **Shell erection begins June 1997**
- **All designs complete May 1998**
- **LSWT drive system delivered May 1998**
- **Midpoint of construction is July 1999**
- **Project complete April 2002. Eight year duration**
- **TSWT is ready for testing on March 2002**

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[illegible]

# Work Breakdown Structure

1000	Site and Infrastructure
2000	Buildings
3000	Auxiliary Process System
4000	Low Speed Wind Tunnel
5000	Transonic Speed Wind Tunnel
7000	Operations (LSWT and TSWT)
8000	Management and Support

# WBS 5000 Transonic Wind Tunnel

## 3rd Tier

5100 TSWT ACOUSTIC ENCLOSURE  
5200 TSWT PRESSURE SHELL  
5300 PRESSURE ISOLATION SYSTEM  
5400 FLOW INTERNALS  
5500 TEST SECTIONS & PLENUM  
5600 TEST SUPPORT EQUIPMENT  
5700 COMPRESSOR & DRIVE SYSTEM  
5800 ELECT, CONTROLS & DATA ACQ  
5900 TEST AND VALIDATION

## 4th Tier

5410 TURNING VANES  
5420 HONEYCOMB  
5430 SCREENS  
5440 HEAT EXCHANGER  
5450 STILL. CHAMBER LINER  
5460 PLENUM EVAC. SYSTEM  
5470 ACOUSTIC BAFFLES  
5480 FLEXIBLE NOZZLE  
5490 COMP FOD SCREEN  
54A0 CHOKE SYSTEM  
54B0 HIGH SPD DIFFUSER LINER

## 5th Tier

5441 COOLING BUNDLES  
5442 FAIRINGS & SUPPORTS  
5443 INTERCONNECT PIPING

# FourthTier Cost Estimates

## WBS 5400 TSWT Flow Internals

WBS	DESCRIPTION	EE (\$K)	RISK (%)	CE (\$K)	DESIGN (%)	TOTAL (\$K)
5410	TURNING VANES	4,275	20%	5,130	10%	5,643
5420	HONEYCOMB	1,019	30%	1,325	10%	1,457
5430	SCREENS	1,400	30%	1,820	10%	2,002
5440	HEAT EXCHANGER	8,056	30%	10,473	10%	11,520
5450	STILLING CHAMBER LINER	2,040	40%	2,856	10%	3,142
5460	PLENUM EVAC. SYSTEM	23,240	20%	27,888	5%	29,282
5470	ACOUSTIC BAFFLES	600	20%	720	15%	828
5480	FLEXIBLE NOZZLE	13,600	30%	17,680	15%	20,232
5490	COMPRESSOR FOD SCREEN	3400	20%	4,080	15%	4,692
54A0	CHOKE SYSTEM	3100	30%	4,030	20%	4,836
54B0	HIGH SPD DIFFUSER LINER	975	40%	1,365	15%	1,570
5400	TOTALS	61,705	25%	77,367	10%	85,204

# National Wind Tunnel Complex

## Cost Estimate

(Dollars in Thousands)

<u>WBS</u>	<u>Description</u>	<u>Estimate</u>
1000	Site and Infrastructure	\$58,270
2000	Buildings	103,074
3000	Auxiliary Process System	114,408
4000	Low Speed Wind Tunnel	386,622
5000	Transonic Speed Wind Tunnel	320,997
7000	Operations (LSWT and TSWT)	89,056
8000	Management and Support	164,015
	<b>Engineering Estimate</b>	<b><u>\$1,207,797</u></b>
	Risk	<u>294,394</u>
	<b>Subtotal</b>	<b><u>\$1,502,191</u></b>
	Bond	12,018
	Escalation	347,140
	Contingency	372,270
	Construction Management	134,017
	Engineering Support	44,672
	<b>Total Construction Budget</b>	<b><u>\$2,412,308</u></b>
	Studies	8,660
	Design	<u>100,800</u>
	<b>PROJECT TOTAL</b>	<b><u>\$2,550,412</u></b>

# **Reduction of Cost Uncertainty**

- **Optimization of wind tunnel circuit**
  - **Configuration**
  - **Internal components size and location**
  - **Acoustical treatment**
- **Optimization of systems for productivity**
  - **Carts/test section/model support**
  - **Isolation valves**
  - **TSWT choke and re-entry**
  - **External balance load path and anchor**

**National Wind Tunnel Complex**  
**Joint Industry Government Team**

**Appendix 9**

**Report from JIGT Support  
Contractors - Sverdrup  
Technology, Inc. and ASE -  
Fluidyne**



# MEMORANDUM

March 9, 1994

TO: Henry Wright, NASA Langley Research Center  
FROM: Ron Hamilton *RH*  
SUBJECT: Report on Sverdrup Participation in the Joint Industry-Government NWTC Project Planning Team

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## 1.0 Introduction

A Joint Industry-Government team was assembled at NASA Langley Research Center to assess the cost, schedule, performance reduction options and implications, and the project management model considering an Industry Consortium execution of the design, construction, and checkout of the complex. The purpose of this team was to develop a consensus program cost and consensus program schedule, based upon a consensus project management model.

Sverdrup Technology, Inc., was contracted, via work order through the Sverdrup LaRC office, to participate on-site in the subject effort. ASE-FluidDyne, under subcontract to Sverdrup, also participated as a part of the Sverdrup team. A copy of the report on the ASE-FluidDyne efforts is included as Attachment 1.

The general scope of the Sverdrup task was to provide an industry position on project scope, project cost estimates, and project schedule for the auxiliary process systems and the two wind tunnels. In addition, the industry perspective on the program management and procurement options was required.

## 2.0 Task Description

The specific scope of the Sverdrup effort was as follows:

- Perform conceptual systems design and cost estimating for the auxiliary process systems required to support the two wind tunnels. Establish cost uncertainty (risk) based on the maturity of the design, certainty of requirements, and the complexity of the systems. Develop estimates of the design and construction cost that are based upon an industrial procurement approach.
- Review the previous cost estimating activities performed by the Facilities Study Office and the Ad-Hoc Review activity performed for the National Wind Tunnel Complex (NWTC) during 1993. The previous cost estimates were used in conjunction with these cost estimates to assist in the development of a consensus cost estimate for the NWTC.

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- Provide recommendations for specific wind tunnel and auxiliary system performance reductions. The recommendations should include identification of the specific performance parameters, the implication of exercising the performance reduction(s) from a customer or capability perspective, the impacts on the rest of the NWTC systems/components, and the cost associated with the performance reduction.
- Provide recommendations for the project management model with particular emphasis on the use of commercial or industrial procurement practices, concurrent design and construction activities (design and build contracts), acquisition strategies, project staffing, and the adders or markups that might be associated with an industrial fixed price contract.
- Provide inputs for the development of the program schedule for the execution of the project that are consistent with concurrent design and construction activities. The schedules were exercised to assess various options and trades.

### 3.0 Task Participants

Sverdrup representatives, along with their dates of participation and area of contribution, are as follows:

Ron Hamilton	2/16/94 - 2/25/94	Project Management
Jim Young	2/16/94 - 2/25/94	Test Equipment
Ward Johnson	2/16/94 - 2/25/94	Structures
Jim Thorington	2/16/94 - 2/25/94	Process Systems
Ed Rimpley	2/16/94 - 2/21/94	Scheduling
Jim Gunn	2/20/94 - 2/25/94	Aerodynamics
Willard Summers	2/22/94 - 2/24/94	Project Management

### 4.0 Task Schedule

The task commenced on 2/15/94. Sverdrup personnel arrived on-site on 2/16/94. All activities were completed on 2/25/94.

### 5.0 Report on Activities

#### 5.1 Project Management

Ron Hamilton, Ed Rimpley, and Willard Summers of Sverdrup participated in discussions regarding project management issues. The major activities in the project management effort

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were generation of a project management model with particular emphasis on the use of commercial/industrial procurement practices and acquisition strategies and adders/markups associated with an industrial fixed price contracting.

The initial effort in this area involved examination of the Boeing project management model and the Government presentation of their understanding of the Industrial Consortium project management model. These models possessed the following features:

- Government pays total capital cost on a cost reimbursable basis.
- A management board, composed of representatives of Government and Industry, provides oversight of the participating group.
- NASA, DoD and other agencies administer the contract between the Government and Industry Joint Venture.
- The Industry Joint Venture contracts for and manages the design, sighting, acquisition and operation of the NWTC.
- Consortium allocates wind tunnel use rights.

Examination of the Boeing Consortium model by Sverdrup raised three key areas of concern:

- How is Government input and expertise obtained in the design process?
- How is the risk to the Government and to the Industry Joint Venture mitigated?
- How does one minimize the schedule impact of the formation of the Industry Joint Venture and Government contract?

Sverdrup developed an alternate Consortium model which addressed these three key issues and presented it to the management group. This model, shown graphically in Attachment 2, has the following features:

- The Government selects and contracts with A/E's for up to 30% design and leads the effort, thereby significantly reducing risk.
- The Industry Joint Venture development occurs concurrently with design development, thus minimizing schedule impact.
- The Industry Joint Venture provides input to the requirements and design (via MOU's) during this phase.
- The Government's technical input and participation is maximized by leading the early effort.
- At the end of the 30% design, the Government contracts with the Industry Joint Venture for detail design and construction of NWTC on a fixed-price basis.
- The design contract with the A/E's would either be novated to the Industry Joint Venture for design completion, or the Industry Joint Venture would negotiate a final design/construction support contract.

The model described above is the Sverdrup recommended model for the Consortium.

## 5.2 Mechanical/Structural (WBS 4000/5000)

Ward Johnson and Jim Young of Sverdrup participated in these discussions. Considerable time and effort was spent in an effort to understand the Concept A estimates made by FSO, AD-Hoc Review, and Boeing. It was felt by the team that the differences must be identified for Concept A in order that it could be used as the model for scaling to Concept D-5. The analysis revealed that there were numerous major differences between the Concept A tunnel estimated by the FSO and Ad-Hoc and the "Boeing Tunnel". During this process FSO explained their assumptions and the basis for the Concept A estimates. These were noted and compared with the limited cost information furnished by the Boeing representatives and from this information an estimate was compiled and labeled concept A-Consortium. It was not evident that Boeing accepted this estimate as representing the position of the Consortium.

The cost estimates required for Concept D-5 were developed from the Consortium estimate for Concept A. The approach used was to scale the cost for Concept A based on the appropriate factors developed from the ratios of volumes, areas, and linear dimensions. Each element of the WBS was reviewed and the applicable scaling factor selected. During this review the risk factor and the design estimate were discussed and adjusted if the team concurred in the modification.

Specific items addressed during the effort were as follows:

- Reviewed/confirmed the Concept A scope of work and basic design approach. Compared quantity take-offs and unit costing between FSO, Sverdrup, Boeing and FluidDyne.
- Reviewed the Babcock proposal to Boeing for fabrication and installation of TSWT pressure shell. Used this information to evaluate/validate group estimates.
- Assisted in development of Joint Industry/Government (JIG) estimates for Concept A and Concept D-5.
- Identified the difference in Boeing and FSO estimates considering basic facility requirements for FSO Concept A and "Boeing Tunnels".
- Confirmed the development of scaling factors used for estimating Concept D-5. Scaling factors were used to develop quantity take-offs by FSO and then standard unit pricing was applied to quantities.

March 9, 1994

- Identified four areas for study that could reduce construction schedule and facility costs. Recommend that further study be initiated in the following:
  1. Hydrotest of Pressure Shell
  2. Contraction Ratio
  3. Plenum Evacuation System
  4. Number of Test Sections and Model Supports
- Developed design/procurement model to minimize schedule requirements. Model depends on preliminary bid of major components, preliminary selection of vendor(s) while final design efforts continue, and final contract negotiation after design completion. This approach not only shortens procurement cycle (i.e., overall schedule) it reduces risk by working with vendor during design process to optimize design details and identifying high cost areas early in the process.
- Evaluated and/or confirmed major activities list and schedule durations associated with preliminary project schedule. Identified major activities not included in schedule. Evaluated and modified accordingly logic used to develop flow charting of project.
- Provided additional input as required to adjust facility design/procurement/construction activities to agree with standard approaches used by industry.

### 5.3 Auxiliary Process Systems (WBS 3000)

The primary task of the subject effort was to develop a consensus cost for the National Wind Tunnel complex (NWTC). Two general sub-tasks were accomplished, 1) developing a Joint Industry-Government Team (JIGT) budget cost for Concept A of the NWTC and, 2) scaling the Concept A cost to the Concept D - Option 5 configuration. This section describes the Auxiliary Process system tasks.

For the first task, the primary focus was resolving the cost and scope differences between the FSO Concept A and the Boeing concept. After reviewing the scope for both the FSO and Boeing estimates, it was obvious there were significant scope differences. The FSO estimate agreed with the scope defined in a report developed by Bechtel for Boeing but it also included a Plenum Evacuation System (PES) for the TSWT. Boeing did not include a PES but agreed the scope described in the Bechtel report was correct. Boeing's costs were evidently based on an earlier concept. The major differences between the FSO cost for concept A and the Boeing cost were quantities of components, length of piping and the PES. Boeing adjusted their cost to more closely reflect the scope in the Bechtel report, and the FSO cost were adjusted to reflect deletion of the PES. In deleting the PES, the cooling water system was also reduced in size

because of the lower heat load. Cost differences between the FSO concept and the Boeing concept remained after the adjustments in the following areas:

- High pressure compressors (due to unit cost for the compressors) \*
- Drier system \*
- Distribution piping for the air system \*
- Storage tanks
- Vacuum system \*
- Distribution piping for the cooling water
- Tunnel cleaning system
- High pressure air calibration system piping (due to unit cost of the piping) \*

\* (Cost differences for these items could not be resolved at the meeting due to lack of detail information on which the Boeing costs were estimated.)

The FSO method of adding risk to the engineering estimate was the largest contributor to the difference in cost.

The second task of scaling up to the Concept D-Option 5 was not possible by multiplication factors since there were significant scope changes involved. The scope changes were:

- Include the PES for the TSWT
- Reduce the continuous 4500 psi flow rate from 140 lbm/sec to 50 lbm/sec
- Reduce the cooling tower capacity from 100 percent installed horsepower to 60 percent installed horsepower.
- Maximum flow rate from the 4500 psi system in 100 lbm/sec for 15 minutes out of every 30 minutes.
- Addition of vitiated air heater for HSCT testing.

Based on the scope changes listed above and the unit costs for components developed for Concept A, the cost for the Concept D-Option 5 auxiliary system was developed. The composite risk factor for the auxiliary system was reduced from 24 percent to 20 percent but it is still added to the engineering estimate.

#### 5.4 Aerodynamics

Jim Gunn of Sverdrup participated in the aerodynamics efforts. Sverdrup supported and checked the cost modeling work associated with changing contraction size. The model, as developed by Frank Steinle, identified the various tunnel components for which initial cost was affected by contraction ratio. A cost algorithm was developed so that costs could be related to the Concept D estimate for a contraction ratio of 12.7. This algorithm indicates that as the

Memo to H. Wright

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contraction ratio decreases from 12.7 the first cost will decrease, reach a minimum, and then increase. This occurs because as the contraction ratio is decreased, the shell steel cost is reduced. However, as contraction ratio decreases, the tunnel losses increase and the cost of the cooler and drive system also increase. As the contraction ratio nears 8 the algorithms indicate that the first cost is minimized but further contraction ratio reduction can cause an increase in first cost for both the drive and the cooler, and these costs will increase faster than the shell cost savings.

An algorithm was also developed for operating cost as a function of contraction ratio. This algorithm shows, as expected, that as contraction ratio decreases the tunnel losses increase, more power is required, and annual operating costs increase.

Studies were also made to evaluate the effects of contraction ratio on flow quality. Results of this analysis generally indicate that flow quality requirements can be met with contraction ratios as low as 8.

The primary conclusion which can be draw from this summary analysis is that the optimum contraction ratio selection is generally an economic issue which depends on the operating scenarios selected, assumed power cost, and desired payback period. Once these parameters have been determined the first cost model can be used to select a configuration for cost evaluation and subsequent verification of the first cost model. Another cost model iteration may then be required.

Proposes studies were discussed with team members. Care should be taken to insure that the studies are integrated.

#### 5.5 Schedule

Ed Rimpley of Sverdrup participated in the scheduling activities. The initial scheduling efforts involved development of high level logic elements for the schedule and their interrelationships. Sverdrup's input was based on experience in executing "fast-track" design/build projects. Various technical sub-groups were utilized to generate the detailed logic elements with associated relationships and assigned preliminary durations. The entire project planning group then reviewed the resulting network and adjusted it until a consensus was reached. Approximately 230 activities were included int he schedule. Sverdrup concurs with the eight-year NWTC project duration, which was the result of the schedule activity, and with the identified critical path.

cc: Sam Pate  
Al Baer  
Willard Summers  
Jim Young

Jim Thorington  
Jim Gunn  
Ward Johnson  
Ed Rimpley

Paul Sensmeier

ATTACHMENT 1

FluiDyne Facilities Group  
Aero Systems Engineering, Inc.  
358 East Filmore Avenue  
St. Paul, MN 55107

February 28, 1994

Sverdrup Technology, Inc.  
Langley Division  
22 Enterprise Parkway  
Suite 350  
Hampton, Virginia 23666

Ref: Subcontract 94S-018  
Work Order CD-9737-OB-92 / 1233-

Sub: Letter Report  
FluiDyne Participation In The Joint Industry-Government  
NWTC Planning Meeting

ASE/FluiDyne participation and contract effort in support of the subject study under the reference Work Order are summarized in the following:

ASE/FluiDyne representatives:

Leon Ring	17-28 February 1994
Tom Moll	16-25 February 1994
Dean Long	16-25 February 1994
Leon Zacho	16-19 February 1994

General

ASE/FluiDyne participated in a joint industry government planning meeting held at Langley Research Center from 16 February 1994 to 28 February 1994. The purpose of the meeting was to produce a project cost estimate, project schedule and program management plan for both the LSWT, TSWT and auxiliary process systems based on best industry practice. ASE/FluiDyne's role in this process was to provide technical expertise in cost review, design maturity/risk assessment and performance/cost trades. Also, ASE/FluiDyne provided recommendations on how to implement industrial practice.

Project Cost Review

ASE/FluiDyne participated in extensive review and modification of project costs to reflect best industry practice. This was initiated with a scope and cost comparisons of FSO and Boeing concept "A" configurations. Since ASE/FluiDyne had previously worked for both Boeing and FSO, we were able to provide some understanding of

scope and cost differences. ASE/FluiDyne presented detailed cost data collected during the Boeing bid process and subsequent cost estimating activities. Bechtel, Westinghouse, Schenck, DSMA and other cost data and scope definitions collected during previous FSO studies was contributed by ASE/FluiDyne.

Scope and cost comparisons of configuration "D5" (National Consensus Requirements) were made. ASE/FluiDyne again contributed detailed scope and costing information to validate a cost build-up. Quick checks on weights, unit costs, labor estimates, etc were made. Qualitative and comparative reviews were based on long term experience in wind tunnel design and construction projects. Risk and design factor recommendations were provided based on an industrial acquisition approach.

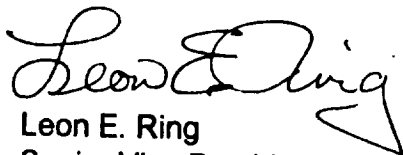
#### Program Schedule

ASE/FluiDyne participated in reviewing program schedule. This included review and modification of defined project activities and associated schedule durations. Preliminary schedules were reviewed with major suppliers (balances, drives, pressure shell). Overall schedule logic was reviewed and recommendations on industrial procurement, concurrent design-construct and industry practices were provided.

#### Studies

Approximately 50 studies defined in previous workshop meetings were evaluated to determine their affect on program schedule. ASE/FluiDyne participated in meetings which resulted in recommendations of funding seven critical studies. The results of these studies will lead to decisions critical in establishing baseline configuration of the tunnels.

AERO SYSTEMS ENGINEERING, INC.



Leon E. Ring  
Senior Vice President

# ATTACHMENT 2 SVERDRUP RECOMMENDED CONSORTIUM MODEL

